University of Alberta

KURA CLOVER (*Trifolium ambiguum* M. Bieb.) AS A LIVING MULCH FOR CEREAL SILAGE PRODUCTION IN CENTRAL ALBERTA

by

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Abstract

Living mulches are a form of intercropping. They involve maintaining a legume cover crop into which an annual crop is seeded. Kura clover (*Trifolium ambiguum* M. Bieb.) is a perennial forage legume that can be used as a living mulch. Our experiment examined the suitability of a kura clover living mulch with two cereal species for silage production. Barley (*Hordeum vulgare* L.) and triticale (X *Triticosecale wittmack*) were seeded at different soil nitrogen levels into unsuppressed and suppressed kura clover living mulches. The presence of the living mulch decreased silage yield compared to cereal monocultures. Herbicide suppression of the living mulch before cereal seeding reduced competition from the kura clover and helped mitigate the yield reductions. Forage quality of the silage was significantly improved when grown with the living mulch. Both the unsuppressed and suppressed living mulches decreased weed pressure and the incidence of cereal leaf diseases throughout the growing season.

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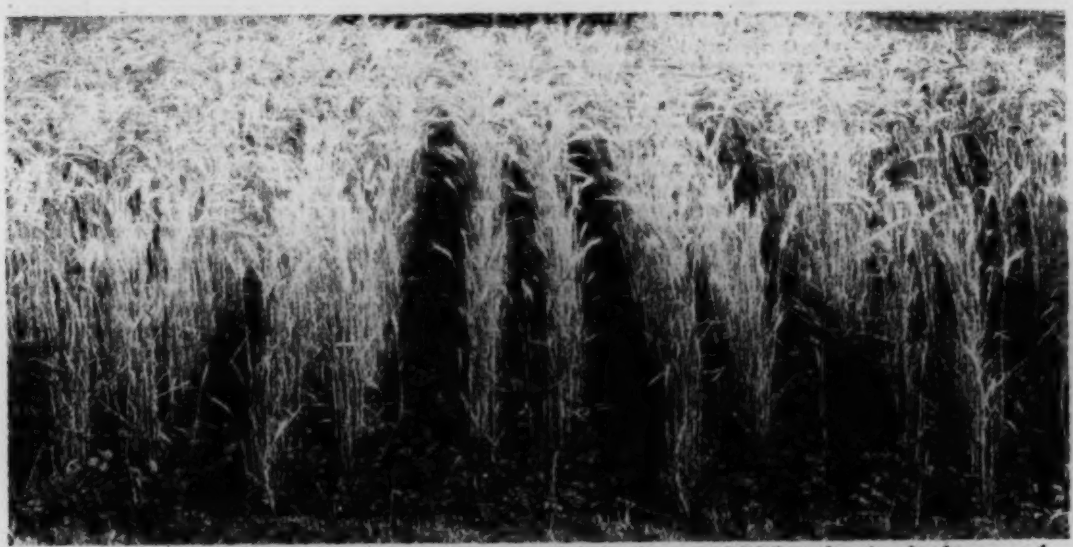
List of Abbreviations

ADF	acid detergent fibre
B	barley
cm	centimetre
CP	crude protein
°C	degrees Celsius
DAP	days after planting
DM	dry matter
ERS	University of Alberta Edmonton Research Station
g	gram
ha	hectare
K	potassium
kg	kilogram
L	litre
LAC	Agriculture and Agri-Food Canada Research Centre in Lacombe
LM	living mulch (non-suppressed)
m	metre
Mg	megagram
mm	millimetre
N	nitrogen
NDF	neutral detergent fibre
P	phosphorus
RFV	relative feed value
S	sulphur
SLM	suppressed living mulch
T	triticale
%	percent

Plots at the Edmonton Research Station in Edmonton, Alberta after cereal seeding in May 2006.



Triticale in a suppressed kura clover living mulch in August 2006 at the Agriculture and Agri-Food Canada Research Centre in Lacombe, Alberta.

Chapter One: Introduction

Crop Production and Sustainability

The Evolution of Conventional Crop Production

'Traditional agriculture' focussed on harnessing the inherent fertility of the soil, its regenerative powers, and species-rich crop rotations for production (Plucknett and Smith, 1986). Diversity was created through the inclusion of legumes to replenish soil nitrogen or the use of intercrops to control agricultural pests (Ruthenberg, 1971; Altieri, 1983; Francis, 1986). The agro-ecosystem mimicked the natural ecosystem in terms of nutrient cycling, pest control, and diversity. After the Second World War, and the introduction of industrial fertilizers, producers began adopting energy-intensive practices. The release of high yielding cereal varieties, which responded to high levels of fertilization, fuelled the demand for synthetic agricultural chemicals (Conway and Pretty, 1991). Producers started applying fertilizer in record amounts to boost yields (Robertson, 1997) and spraying pesticides for crop protection. This contributed to a dramatic increase in food production to satisfy the appetite of an ever-increasing world population (Tilman, 1999). Labour-intensive, diverse agro-ecosystems were quickly replaced with the energy-intensive, chemical-based agriculture prevalent today.

Society's Views on Agricultural Production and Sustainability

Society has noticed the heavy reliance of agricultural production on synthetic chemical inputs and is starting to question its environmental sustainability (Conway and Barbier, 1990; Altieri, 1999). Over two million metric tons of active pesticide ingredients are applied annually, 79% of this in the temperate zone of North America (Bird et al., 1990). In Canada, approximately 73% of all farms involved in crop production apply pesticides (Statistics Canada, 2001). On the prairies, 65% of farms in Alberta, 83% in Saskatchewan, and 77% in Manitoba make pesticides part of their production plan (Statistics Canada, 2001). The use of synthetic chemicals in food production has resulted in numerous environmental problems. Pesticide residues can be found in groundwater, drinking water, and on food products (Conway and Pretty, 1991) in amounts ranging from safe to hazardous, depending on the situation. Consumers want to be assured that the food they purchase has not been produced in a manner resulting in soil, water, or air pollution (Junkins et al., 2005). Governments are drafting policies which focus on increasing the environmental friendliness of crop production. For example, in Canada a five-year plan containing specific goals for air and water quality levels, soil structure preservation, and increasing agricultural biodiversity has been developed (Junkins et al., 2005). This movement towards improving agricultural sustainability is prompting producers and researchers alike to find new methods of decreasing synthetic chemical use in crop production.

What does 'Sustainable Agriculture' mean and how can it be achieved?

In Canada, sustainable agriculture "integrates environmental, economic, and social interests in a way that allows today's needs to be met without compromising the ability of future generations to meet their own needs" (Lefebvre, 2005). For this project, it has been thought of as involving "integrated systems of agricultural production less dependent on high inputs of energy and synthetic chemicals, and more management-intensive than conventional monocultural systems" (Edwards, 1987). We are striving to improve the quality of the natural resources involved in crop production by adopting ecologically sound management techniques. These techniques could also improve the economic sustainability of producers by lowering input costs. Using crop rotations to combat disease and pest outbreaks, legumes to provide nitrogen, and intercrops to increase biodiversity are just a few examples of ways to create sustainable systems (Altieri, 1995). Producers are realizing the benefits from reducing their synthetic chemical inputs and adopting sustainable production practices (Jordan et al., 1997). Research must increase in this area to ensure producers have the information required when searching for ways to improve their farms' sustainability.

Issues with Conventional Crop Production

Nitrogen

Nitrogen is considered the most important nutrient in crop production. It is often the limiting factor of plant growth. It was originally supplied to crops through the inclusion of legumes in rotation (Gilland, 1993) or the application of organic wastes (Gilland, 1993; Frink et al., 1999). In 1908, a process in which atmospheric nitrogen is combined with hydrogen to produce ammonia, a plant-usable form of nitrogen, was developed

(Gilland, 1993; Frink et al., 1999). This process was refined and the first ammonia fertilizer manufacturing plant was opened in 1914. New techniques of producing different types of nitrogen fertilizer, such as nitrate and urea, soon followed (Frink et al., 1999). Nitrogen fertilizers became widely available for use by producers.

Nitrogen fertilizer consumption has been steadily increasing (Conway and Pretty, 1991; Vitousek et al., 1997; Frink et al., 1999). One problem with nitrogen fertilizers is that they have low use-efficiencies. This means not all the fertilizer applied is utilized by the crop. Under certain conditions, up to 70% of the nitrogen applied is lost from the soil (Conway and Pretty, 1991). Crop plants typically recover between 50 and 70% of the fertilizer applied (Allison, 1966), with 10 to 40% staying in the soil, 10 to 30% lost via volatilization, and 5 to 10% lost through leaching (Westerman et al., 1972). This loss of fertilizer nitrogen impacts the global nitrogen cycle (Gilland, 1993; Vitousek et al., 1997; Frink et al., 1999).

The unused fertilizer can be converted into nitrate or nitrous oxide (Conway and Pretty, 1991; Frink et al., 1999). Nitrate can leach out of the soil and enter ground or surface water (Cowell and Doyle, 1993; Campbell et al., 1994). Nitrate alters aquatic ecosystems through eutrophication and acidification, damaging fish and waterfowl habitats (Conway and Pretty, 1991; McCracken et al., 1994; Vitousek et al., 1997; Carpenter et al., 1998). Nitrous oxide is a greenhouse gas (Albritton et al., 1995; Vitousek et al., 1997) 310 times more powerful than carbon dioxide (Hutchison et al., 2005). Annual losses of nitrous oxide from fertilized soils can reach 40 kg N ha^{-1} (Ryden and Lund, 1980). As the rate of nitrogen fertilization increases, so do the rates of nitrogen loss and their effect on the environment (Eichner, 1990).

Weeds

A weed is an unwanted plant that interferes with crop production. Currently, over 250 plant species are considered agricultural weeds (Altieri, 1988). Weeds compete with crop plants for sunlight, water, nutrients, and space (Berkowitz, 1988; Radosevich et al., 1997). Left uncontrolled, they can seriously impact crop yield and quality (Sen, 1988; Aldrich and Kremer, 1997). In addition to this, weeds can harbour pathogens and insect pests. This leads to further crop damage (Sen, 1988).Weed control is, therefore, an integral part of crop production.

Historically producers combated weeds with cultural management practices, such as tillage and crop rotation (Froud-Williams, 1988; Aldrich and Kremer, 1997). Current methods of weed control include cultural control, crop rotation, mechanical control, tillage, and chemical control, herbicides (Radosevich et al., 1997). Tillage is effective at controlling weeds, but can increase soil erosion, compaction, and moisture loss (Zimdahl, 2004). Many producers have moved away from tillage to no- or zero-tillage regimes. This has increased the use of herbicides to control weeds (Aldrich and Kremer, 1997). Worldwide, there are over 125 different herbicides registered for use (Altieri, 1988). Over 80% of the pesticides purchased in the United States are herbicides (Radosevich et al., 1997). The cost to develop a new herbicide ranges from 20 to 50 million dollars American (Radosevich et al., 1997), which must be recovered from sales. In Alberta, producers spend around 330 559 million dollars Canadian on synthetic pesticides annually (Statistics Canada, 2001), of which roughly 80% are herbicides. This is a substantial production cost (Zimdahl, 2004).

Herbicides can damage the environment. They injure non-target organisms, pollute ground and surface water (Conway and Pretty, 1991; Radosevich et al., 1997; Zimdahl, 2004), contaminate soil due to residual properties (Radosevich et al., 1997), and lead to the emergence of herbicide-resistant weeds (Froud-Williams, 1988; Hall et al., 1999). In order to control these resistant weeds, producers will often apply two different herbicide classes to their fields. This results in an increase in the use of chemicals for weed control (Hall et al., 1999). Weed control in North America has become dependent on herbicides the use of zero-tillage and direct seeding increased. Therefore, we need to continue to develop more sustainable weed control measures.

Diseases

Plant diseases decrease crop yield and quality (Singh, 2001). In extreme situations, they lead to complete crop failures. This was the case with the wheat stem rust (*Puccinia graminis* Pers.:Pers. F. sp. *tritici* Eriks. & E. Henn.) epidemics in Canada in 1916, 1927, 1935, and 1954 (Bailey et al., 2003). Crop diseases became a serious problem with the advent of agricultural intensification. High-yielding cereal varieties spur producers to apply more fertilizer and chemicals for production (Singh, 2001), which influence crop-disease interactions. For example, the over-application of nitrogen fertilizer results in lush, dense foliage. Certain pathogens thrive in the humid conditions created by the dense canopy, increasing infection rates (Palti, 1981; Dorrance, 1994; Turkington, 2003). Fields are composed of genetically identical plants, creating a situation where every plant is a potential host (Palti, 1981; Singh, 2001). The release of resistant-crop cultivars helped decrease crop infection levels (Carlile, 1995; Turkington, 2003). After a few years, however, the resistance of the cultivar may break down due to the selection pressure exerted on the pathogen and its ability to mutate. This allows for the proliferation of plant diseases within the field (Carlile, 1995; Singh, 2001). Breeders must continually develop new cultivars with different modes of resistance to stay ahead of the pathogens. Numerous pathogens can over-winter in crop stubble (Palti, 1981; Singh, 1989; Dorrance, 1994). This stubble was once incorporated into the soil, creating a barrier between the new crop and the pathogen. Zero-tillage regimes can allow infected stubble to remain on the soil surface, from which pathogens can move to healthy crop tissue the following season (Palti, 1981).

Fungicides are a common strategy for disease control throughout the world (Singh, 2001). They prevent disease development, or stop disease progression if infection has already occurred (Cook and King, 1984; Agrios, 1997; Singh, 2001). Fungicides are effective, but have the potential to strain the health of the environment and the pocketbook of the producer. They do not provide complete disease control as pathogens can develop resistance to them (Carlile, 1988). They can also negatively affect beneficial soil micro-organisms (Saskatchewan Agriculture and Food, 1994). In addition to off-target effects, fungicide applications are difficult to time to ensure maximum control and/or protection (Palti, 1981; Saskatchewan Agriculture and Food, 1994). As with other agri-chemicals, fungicides are time-consuming and costly to produce. It can take upwards of 100 million dollars American, and nine years, to bring a new fungicide to the market. Each application brings new questions about the long-term effectiveness and utility of fungicides for disease control (Carlile, 1995).

Cereal Production

Over the past 35 years, world agricultural production has doubled (Food and Agriculture Organization, 1997) in order to keep pace with the nutritional demands of an increasing world population. Annual nitrogen fertilizer use has increased 6.87 times to help fuel this growth (Food and Agriculture Organization, 1997). Cereal crops account for over 60% of all human calories (Cassman et al., 2003). Grain demand will continue to rise along with the population. The demand for feed grains will cause cereal production to double as more meat is consumed (Tilman, 1999). The new pressures for higher grain yields will most likely lead to an increase in agri-chemical use, as producers seek to maximize yields.

With over 6.6 million head of cattle and calves in Alberta (Alberta Agriculture, Food and Rural Development, 2001), livestock feed is in high demand. Cereal crops, such as barley (*Hordeum vulgare* L.) and triticale (X. *Triticosecale wittmack*), are grown for silage to meet this need. Barley is the second most important cereal crop in Alberta, sown on approximately 1.98 million hectares. Of this area, 35% is seeded for silage (Tekauz, 2003). Silage production often requires more nitrogen (10 to 20 kg N ha^{-1}) than a grain crop (Baron et al., 2000) as the whole plant is harvested for use. Barley and triticale silage are starting to be sown with legumes to help reduce the amount of fertilizer applied, increase feed quality, and stabilize yields (Baron et al., 2000). Legumes have long been seeded with grasses in pasture production, providing stable yields with few inputs. This system could be applied to cereal production with the hope of decreasing the reliance on chemicals for grain and silage production.

Forage Legumes and Cereal Production

Introduction to Forage Legumes

One option to address the issue of agricultural sustainability is a legume-based cropping system. Forage legumes create their own nitrogen supply through a symbiotic association with rhizobia (*Rhizobium* spp.), which are common soil microbes (Heichel and Barnes, 1984; Ledgard and Steele, 1992). This decreases their reliance on soil nitrogen (Chalk, 1998). Rhizobia infect legume roots, forming nodules. In these nodules, they reduce atmospheric dinitrogen gas to ammonia, a plant-usable form of nitrogen (Peoples et al., 1995). The rate of biological dinitrogen fixation varies among species (Baruddin and Meyer, 1989), and can range from 2 to over 300 kg N ha^{-1} $year^{-1}$ (Peoples et al., 1995). The fixed nitrogen can enter the soil through the decomposition of leaves, roots, and nodules, or the release of excess nitrogen from growing roots (Ta et al., 1986; Russelle et al., 1994; Peoples et al., 1995).This nitrogen is then available for use by companion crops or crops grown the following year (Heichel and Barnes, 1984; Peoples et al., 1995; Chalk, 1998; Drinkwater et al., 1998).

Biological dinitrogen fixation has the potential to replace, or reduce, nitrogen fertilizer applications (van Kammen, 1997). It has been estimated that 25 to 100% of a cereal crop's nitrogen needs could be met with biologically fixed nitrogen (Heichel and Barnes, 1984; Zemenchik et al., 2000). In addition, legumes also benefit annual cropping by: increasing soil health, structure, organic matter, and productive life (Drinkwater et al., 1998), reducing disease problems (Curl, 1963), decreasing weed pressure (Stopes et al., 1996; Sullivan, 2003), and increasing grain yields (Ta and Faris, 1990; Stopes et al., 1996; Chalk, 1998).

Legume-Green Manures

Legume green manures are one method of using biological dinitrogen fixation to supply nitrogen to annual cereal crops. A green manure is a legume crop grown for one year to either increase soil nitrogen, prevent soil erosion (Smith et al., 1987; Sullivan, 2003), or to decrease weeds and diseases (Sullivan, 2003). The legume is then killed, chemically or mechanically, before seeding the annual crop. This allows the nitrogen that has accumulated in the legume plants to be incorporated into the soil (Smith et al., 1987; Hesterman, 1988). Legume green manures supply succeeding grain crops with nitrogen and, consequently, increase yields and quality (Smith et al., 1987; Badaruddin and Meyer, 1990; Stopes et al., 1996; Shrestha et al., 1999; Bullied et al., 2002). The main drawback of this system is that the amount and availability of the nitrogen decreases two to three years after legume incorporation (Ta and Faris, 1990).

Grass-Legume Pastures

Pastures often contain mixtures of grass and legume species to provide material for grazing, hay, or silage. The inclusion of a legume benefits grass growth and development (Dilz and Mulder, 1962; Simpson, 1976). Nitrogen can be transferred from the legume to the grass through its release from legume litter, root and nodule decomposition (Ta et al., 1986; Russelle et al., 1994; Peoples et al., 1995) and the excretion of excess amounts into the soil from actively growing roots (Haystead and Marriott, 1979; Ledgard and Steele, 1992). Nitrogen is also directly transferred between grass and legume roots (Simpson, 1976). The amount of nitrogen transferred varies among legume species. For example, Simpson (1976) found that white clover (*Trifolium repens* L.) transferred up to 571 kg N ha^{-1} to orchardgrass (*Dactylis glomerata* L.) over a three year period, while red clover (*Trifolium pratense* L.) transferred 304 kg N ha^{-1}.

Disadvantages of grass-legume pasture systems include competition between the legume and grass for resources (Simpson, 1965; Sanderson and Elwinger, 2002), which can lead to decreased nitrogen fixation (Ledgard and Steele, 1992), and variability in the amount of nitrogen fixed and released by the legume (Smith et al., 1987; Mallarino et al., 1990).

Intercropping

Introduction to Intercropping

Intercropping is the cultivation of two or more crop species in the same space and time (Ofori and Stern, 1987; Vandermeer, 1989; Liebman, 1995). Intercrops are prominent in parts of Africa, Asia, India, and South America (Vandermeer, 1989; Fujita et al., 1992; Liebman, 1995). They have predominantly been used by subsistence farmers in developing nations, but there is growing interest in adopting them to the mechanized crop production found in North America (Vandermeer, 1989; Liebman, 1995). Enormous variety exists in the types of plants which are intercropped. Annuals can be sown with annuals or perennials, perennials with perennials, root crops with fruit trees, or legumes with cereals (Liebman, 1995). Crops can be sown at the same time, or staggered, and their harvests may be simultaneous or successive (Ofori and Stern, 1987; Liebman, 1995). Each producer adapts the system to meet his personal food, fuel, and cash goals (Liebman, 1995).

The main reasons for intercropping are year-round food production (Vandermeer, 1989), enhanced yields, yield stability, and improved resource use (Lynam et al., 1986; Vandermeer, 1989; Liebman, 1995). The improved resource use of intercrops is thought to support the increase in yield and yield stability. If the component crops complement each other in growth form and fertility requirements, they better exploit the nutrients, water, space, and sunlight available (Trenbath, 1986; Fujita et al., 1992; Liebman, 1995). Intercrop components can also facilitate each other's growth. For example, leguminous crops fix nitrogen. This nitrogen can be released into the soil and become available for other plants, boosting their production (Ofori and Stern, 1987; Vandermeer, 1989). Other benefits of intercropping include weed suppression (Litsinger and Moody, 1976; Hartl, 1989; Trenbath, 1993), increased disease control (Litsinger and Moody, 1976; Altieri and Liebman, 1986; Trenbath, 1993; Liebman, 1995), and soil improvements (Liebman, 1995; Anil et al., 1998).

Cereal-Legume Intercrops

Cereal-legume intercrops are currently grown throughout the world (Rao, 1986; Ofori and Stern, 1987; Anil et al., 1998). One of the reasons for their success is a difference in growth habits. The taller, erect cereal leaves capture light for growth, but also allow it to filter down to the lower legume canopy (Ofori and Stern, 1987). The broad, horizontal legume leaves intercept the majority of the light making it past the cereal plants. This drastically decreases the amount of sunlight wasted on the soil surface (Ofori and Stern, 1987). In one experiment, the light interception of wheat (*Triticum aestivum* L.)-clover (*Trifolium* spp.) intercrops was measured (Reynolds et al., 1994). It was found that the ground cover created by the legume increased the total amount of light intercepted compared to wheat monocultures. In addition to this, the wheat-clover plots yielded more than the wheat monoculture plots (Reynolds et al., 1994). Cereal and legume roots also differ in growth habit, rooting depth, and nutrient uptake. This could minimize nutrient and water competition, while more efficiently utilizing soil resources (Rao, 1986; Fujita et al., 1992; Anil et al., 1998).

Benefits of cereal-legume intercrops include enhanced yields (Searle et al., 1981; Berkenkamp and Meeres, 1987; Fujita et al., 1992), improved quality (Wall et al., 1991; Jedel and Helm, 1993; Anil et al., 1998; Mpairwe et al., 2002; Ross et al., 2004a), weed suppression (Hartl, 1989; Izaurralde et al., 1993; Liebman and Dyck, 1993; Moynihan et al., 1996; Ross et al., 2004b), and nitrogen inputs (Searle et al., 1981; Fujita et al., 1992; Izaurralde et al., 1993; Ghaffarzadeh, 1997). Often, more nitrogen is produced by the legume than it needs. This excess nitrogen is released into the soil, where it is available for uptake by other plants (Trenbath, 1976; Fujita et al., 1992; Anil et al., 1998). Intercropping a cereal and legume allows producers to take advantage of the nitrogen contributed to the system by the legume and decrease the amount of nitrogen fertilizer applied (Rao, 1986; Ofori and Stern, 1987).

A corn (*Zea mays* L.) and soybean (*Glycine max* L.) intercrop yielded 36.5% more biomass than a corn monoculture (Searle et al., 1981). An unfertilized silage corn-red clover (*Trifolium pratense* L.) crop grown in Ontario produced yields equivalent to those of the fertilized corn monoculture and increased silage digestibility (Wall et al., 1991). One limitation to the use of intercrops on the Canadian prairies is our climate, as intercrops are mainly found in more tropical locations. However, cereal-legume intercrops containing species currently sown on the prairies, have the potential to be successfully adopted by producers.

Living Mulches

One form of intercropping, called a living mulch, involves maintaining a legume cover crop into which an annual crop is seeded (Altieri, 1995; Hartwig and Ammon, 2002). Living mulches can: supply the annual crop with nitrogen (Ebelhar et al., 1984; Ammon, 1998; Leary and DeFrank, 2000; Hartwig and Ammon, 2002), reduce soil erosion (Wall et al., 1991; Altieri, 1995; Ammon, 1998; Hartwig and Ammon, 2002), decrease surface water runoff (Hartwig and Ammon, 2002), reduce weed pressure (Altieri, 1995; Ammon, 1998; Leary and DeFrank, 2000), decrease disease severity (Altieri, 1986; Altieri, 1995; Leary and DeFrank, 2000), and improve soil structure and health (Raimbault and Vyn, 1991; Altieri, 1995; Hartwig and Ammon, 2002).

Living Mulches and Corn Production

Living mulches, utilizing a variety of forage legumes, have been studied for use in corn production in North America (Vrabel, 1983; Ebelhar et al., 1984; Scott et al., 1987; Echtenkamp and Moomaw, 1989; Ammon, 1998; Leary and DeFrank, 2000; Zemenchik et al., 2000). A suppressed white clover living mulch produced enough nitrogen to meet the requirements of a sweet corn crop, resulting in yields equal to or greater than those of a fertilized corn monoculture crop (Vrabel, 1983). Ebelhar et al. (1984) found that a living mulch of hairy vetch (*Vicia villosa* Roth.) supplied the equivalent of 90 to 100 kg N ha^{-1} to a corn crop. The legume also increased successive corn yields by 2.5 Mg ha^{-1} (Ebelhar et al., 1984). In a corn-red clover living mulch system, the red clover decreased soil losses by 46 to 78% compared to the unfertilized corn monoculture, while increasing silage yields (Wall et al., 1991).

Living Mulches and Wheat Production

Wheat has been successfully sown into a variety of clover living mulches. Garand et al. (2001) investigated the potential of a red clover living mulch to supply nitrogen to spring wheat. They found that the living mulch supplied the equivalent of 80 kg N ha^{-1} to the wheat crop, meeting most of its nitrogen requirements (Garand et al., 2001). Wiersma et al. (2005) seeded spring wheat into an established living mulch of red clover. The living mulch released excess nitrogen into the soil, which was utilized by the crop. This lowered the need for nitrogen fertilizer applications (Wiersma et al., 2005). Two successive winter wheat crops were sown into a living mulch of white clover and harvested for grain (Jones and Clements, 1993). The white clover did not interfere with combining and increased the grain yield of the second crop by 25% (Jones and Clements, 1993).

Living Mulches and Barley Production

Living mulch-like intercrops have also been employed in barley production, both in Canada (Kunelius et al., 1992; Rees et al., 1999; Ross et al., 2004a) and other parts of the temperate world (Stewart et al., 1980; Moynihan et al., 1996). In Atlantic Canada, barley is often cropped with an annual legume, such as red clover, for grain or forage production (Kunelius et al., 1992). In a study from New Brunswick, barley was under-seeded with red, Persian (*Trifolium resupinatum* L.), and alsike (*Trifolium hybridum* L.) clovers (Rees et al., 1999). The objectives of the trial were to see if the clovers would improve soil health and reduce nitrogen fertilizer applications. Rees et al. (1999) found that barley-clover yields were comparable to those from conventionally fertilized barley monocultures. Soil organic matter and nitrogen levels both increased as a result of the presence of the clovers (Rees et al., 1999).

Potential Forage Legume for a Living Mulch

Kura clover (*Trifolium ambiguum* M. Bieb.) is a long-lived perennial, originating in the Caucasus region of Russia (Speer and Allison, 1985; Sheaffer and Marten, 1991; Taylor and Smith, 1998). It is well adapted to a wide range of climatic conditions and tolerates poorly drained, acidic, and infertile soils (Moore, 2003). Kura clover is extremely winter hardy and drought tolerant (Speer and Allison, 1985; Taylor and Smith, 1998). It has a prostrate growth habit (Speer and Allison, 1985) and is strongly rhizomatous (Speer and Allison, 1985; Forde et al., 1989; Genrich et al., 1998). Kura clover is used in pastures, for hay, and silage. It has similar nutritional qualities to those of white clover (Speer and Allison, 1985; Taylor and Smith, 1998). Drawbacks of this species include slow establishment (Speer and Allison, 1985; Taylor and Smith, 1998; Seguin et al., 1999), low herbage production the first year after seeding (Speer and Allison, 1985), slow nodulation (Speer and Allison, 1985; Townsend, 1985; Seguin et al., 2001), and its ability to cause bloat in cattle (McGraw and Nelson, 2003).

Kura clover can fix upwards of 155 kg N ha^{-1} $year^{-1}$ (Seguin et al., 2000). Adding it to a pasture increases the quality of the material, while decreasing nitrogen fertilizer applications (Sleugh et al., 2000; Zemenchik et al., 2002). When grown in pastures with smooth brome, the fertilizer nitrogen replacement value of kura clover ranged from 74 to 325 kg N ha^{-1} (Zemenchik et al., 2001), making this system nitrogen self-sufficient. Kura clover is currently being evaluated as a living mulch for corn production (Zemenchik et al., 2000; Affeldt et al., 2004; Duiker and Hartwig, 2004). Zemenchik et al. (2000) seeded corn into established plots of kura clover that were either left alone or sprayed with a herbicide. They found no significant difference in yield between the living mulch system and conventionally fertilized corn plots (Zemenchik et al., 2000). Kura clover appears to be ready for inclusion as a living mulch in other cereal production systems.

Potential Drawbacks of Living Mulches

One of the main issues with using a living mulch is competition between it and the main crop. In pastures, grasses tend to have the advantage over legumes (Haynes, 1980). This could pose a problem where a vigorous annual cereal has been seeded into a legume-living mulch. Above-ground competition for sunlight and space would occur. Some legumes, particularly clovers, have high light demands. The taller cereal can shade the living mulch, reducing legume growth (Haynes, 1980; Hay and Hunt, 1989; Sheaffer, 1989). Less growth means less biologically fixed nitrogen produced, decreasing the nitrogen benefit of the living mulch.

Competition also occurs below-ground for nutrients and water. In high nitrogen soils, the number of legume root nodules decreases, causing a reduction in the amount of nitrogen fixed. In order to meet its nitrogen needs, the legume will then compete with the intercropped cereal for soil nitrogen (Haynes, 1980). Grass roots tend to be longer, thinner, and more highly branched than those of clovers. This creates a situation where most of the clover roots could be in direct competition with grass roots for soil nutrients, while most of the grass roots would be without competition (Haynes, 1980). On the other hand, clovers have long taproots, which allow them access to deep soil water (Sheaffer, 1989). This would give the clover the advantage during droughts.

Perennial legumes will have well developed roots systems the spring following establishment. The cereal being seeded into the established clover could be at a disadvantage in terms of early season nutrient and water access. Chemical suppression of the living mulch might then be necessary to ensure cereal establishment. For example, corn seeded into unsuppressed alfalfa experienced a 96% yield reduction compared to corn sown alone (Eberlein et al., 1992). The alfalfa plants were more developed than the corn seedlings and out-competed them for resources. Other benefits of living mulches, such as soil improvements (Touchton et al., 1984; Duiker and Hartwig, 2004), weed control (White and Scott, 1991), and disease suppression (Francis, 1989), are variable and might not occur with all species or in all growing environments. Cereal-legume living mulch systems need to be developed for specific regions and cropping systems in order to be beneficial to crop production in Canada.

Statement of Purpose

Our objective was to determine the suitability of a legume living mulch as a means of decreasing the chemical reliance of cereal production in central Alberta. One living mulch system was designed; a two-year cereal silage rotation seeded into a kura clover living mulch. We aimed to determine the effects of the kura clover living mulch on silage yield, composition, and quality under different nitrogen and suppression regimes. In addition, the effects of the living mulch on cereal emergence, growth, disease incidence, and weed pressure were measured to provide insight into the system's dynamics and potential benefits.

We are seeking to increase our understanding of the dynamics between a legume living mulch and cereal crops. We strove to develop reduced-input silage production systems, while maintaining yields. There is growing support for the adoption of reduced agri-chemical cropping systems as input prices rise, commodity prices fluctuate, and environmental awareness increases. The purpose of these trials was to determine if kura clover living mulches are feasible for cereal silage production in Alberta.

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Chapter Two: Silage Yield, Species Composition, and Forage Quality

Null Hypotheses

Barley grown following barley will not be significantly different from barley grown following triticale at the same soil nitrogen level for silage dry matter yield, species composition, and forage quality.

Cereals grown alone will not be significantly different from cereals grown with kura clover living mulches at the same soil nitrogen level for silage dry matter yield, species composition, and forage quality.

Cereals grown with a suppressed kura clover living mulch will not be significantly different from cereals grown with a non-suppressed kura clover living mulch at the same soil nitrogen level for silage dry matter yield, species composition, and forage quality.

Introduction

Kura clover (*Trifolium ambiguum* M. Bieb.) is a long-lived perennial legume, originating in the Caucasus region of Russia (Speer and Allison, 1985; Sheaffer and Marten, 1991; Taylor and Smith, 1998). It is well adapted to a wide range of climatic conditions and tolerates poorly drained, acidic, and infertile soils (Moore, 2003). Kura clover is extremely winter hardy and drought tolerant (Speer and Allison, 1985). It also has a prostrate growth habit (Speer and Allison, 1985) and is strongly rhizomatous (Forde et al., 1989; Genrich et al., 1998). Currently, kura clover is used in pastures, for hay, and silage in parts of Europe, Australia, the United States, and Canada. It has similar nutritional qualities to those of white clover (*Trifolium repens* L.) (Speer and Allison, 1985; Taylor and Smith, 1998). Limitations of this species include slow establishment (Seguin et al., 1999), low herbage production in the year of establishment (Speer and Allison, 1985), and slow nodulation (Townsend, 1985; Seguin et al., 2001).

A living mulch is a form of intercropping. It involves maintaining a legume cover crop into which an annual crop is seeded (Altieri, 1995; Zemenchik et al., 1998; Hartwig and Ammon, 2002). Often, that annual crop is a cereal. The benefits of a living mulch include: supplying the cereal crop with nitrogen (Ebelhar et al., 1984; Ammon 1998; Zemenchik et al., 1998; Leary and DeFrank, 2000), reducing soil erosion (Wall et al., 1991; Altieri, 1995), decreasing surface water runoff (Hartwig and Ammon, 2002), and improving soil structure and soil function (Raimbault and Vyn, 1991; Altieri, 1995).

Kura clover has been evaluated as a living mulch for corn (*Zea mays* L.) production (Zemenchik et al., 2000; Affeldt et al., 2004; Duiker and Hartwig, 2004). Zemenchik et al. (2000) seeded corn into established plots of kura clover that were either suppressed with glyphosate at varying rates or unsuppressed. They found no significant difference in corn yield between the suppressed living mulch plots and the conventionally grown and fertilized corn plots (Zemenchik et al., 2000). Winter wheat (*Triticum aestivum* L.) has been sown into a kura clover living mulch and harvested for silage (Contreras-Govea et al., 2006). Dry matter yield of the winter wheat-kura mixture was less than that of sole winter wheat, but double that of sole kura clover.

Barley (*Hordeum vulgare* L.) is the second most important cereal crop in Alberta, Canada, sown on approximately 1.98 million hectares. Of this area, 35% is seeded for silage (Tekauz, 2003). Triticale (X *Triticosecale wittmack*) is another cereal crop commonly grown for silage in Alberta. Silage production can be input intensive, and often requires 10 to 20 kg N ha^{-1} more than grain crops (Baron et al., 2000). Herbicides and fungicides are also applied throughout the growing season to combat weeds and diseases. With the rising cost of these agri-chemicals, producers are in search of cropping systems that can improve their economic and environmental sustainability. Living mulches have the potential to accomplish this for silage production.

Cereal-legume intercrops have been previously studied in Canada (Kunelius et al., 1992; Thompson and Stout, 1997; Rees et al., 1999; Ross et al., 2004). In Atlantic Canada, barley is often cropped with an annual legume, such as red clover (*Trifolium pratense* L.), for grain or forage production (Kunelius et al., 1992). In New Brunswick, barley was underseeded with red, Persian (*Trifolium resupinatum* L.), and alsike (*Trifolium hybridum* L.) clovers (Rees et al., 1999) and the barley-clover yields were comparable to those from conventionally fertilized barley monocultures. Soil organic matter and nitrogen levels both increased due to the presence of the clovers (Rees et al., 1999). The addition of Persian clover to a barley-annual ryegrass (*Lolium multiflorum* L.) mixture increased dry matter yields, improved forage quality, and reduced nitrogen fertilizer needs in British Columbia (Thompson and Stout, 1997). Barley and triticale intercropped with berseem clover (*Trifolium alexandrium* L.) produced high forage yields in Alberta (Ross et al., 2004).

Little information is available on kura clover living mulches for cereal silage production. To date, most of the studies have been conducted with corn-kura clover living mulch systems in the United States. The objective of this experiment was to assess the compatibility of a kura clover living mulch with barley or triticale for silage production in central Alberta. The effects of non-suppressed and suppressed kura clover living mulches on silage yield, species composition, and forage quality were examined.

Materials and Methods

Treatments and Measurements

Field experiments were conducted at the University of Alberta Research Station (ERS) in Edmonton, Alberta and the Agriculture and Agri-Food Canada Research Centre in

Lacombe (LAC), Alberta over two years; Year 1 (2006) and Year 2 (2007). Plots at ERS and LAC were established on black chernozemic soils. Soil pH at the test sites ranged from 6.3 to 7.3. 'Cossack' kura clover plots were established in June 2005 at ERS with a 4-row disc drill, and at LAC with a Conservpak® air seeder (Conserva Pak Seeding Systems, Indian Head, SK). Kura seeding rate was 12 kg ha^{-1}, depth was 1.5 to 2 cm, and row spacing was 30 cm at ERS and 23 cm at LAC. Kura seed was inoculated with a commercially available mixture of *Rhizobium leguminosarum* biovar *trifolii* strains prior to sowing. 'Seebe barley' and 'AC Morgan' oats (*Avena sativa* L.) were seeded at a rate of 300 seeds m^{-2} and row spacing of 23 cm into designated 'kura-free' plots in order to establish the continuous barley and rotational cereal sequences. Soil P, K, and S levels were maintained based on soil test recommendations (Norwest Labs, Edmonton, AB). ERS plots were hand-weeded. In September 2005, both sites were mowed with a sickle mower and the plant material raked off the plots.

The experiment was arranged in a split-plot, randomized complete block design with four replications per site. Sub-plot dimensions were 2.76 x 6 m at ERS and 3.66 x 7.62 m at LAC. Nitrogen was the main plot treatment and rotation was the sub-plot treatment. The three nitrogen (N) application treatments were: (1) low soil N (90 kg N ha^{-1} in Year 1 and 11 to 76 kg N ha^{-1} in Year 2); (2) medium soil N (150 kg N ha^{-1} in Year 1 and 93 to 150 kg N ha^{-1} in Year 2); and (3) high soil N (225 kg N ha^{-1} in Year 1 and 176 to 225 kg N ha^{-1} in Year 2). The six rotation treatments included: (1) B-B (barley in Years 1 and 2); (2) T-B (triticale in Year 1 and barley in Year 2); (3) LM + B-B (kura clover living mulch plus barley in Years 1 and 2); (4) LM + T-B (kura living mulch plus triticale in Year 1 and kura living mulch plus barley in Year 2); (5) SLM + B-B (suppressed kura living mulch plus barley in Years 1 and 2); and (6) SLM + T-B (suppressed kura living mulch plus triticale in Year 1 and suppressed kura living mulch plus barley in Year 2). A map of the main and sub-plot treatments from ERS can be found in Appendix 1. Glyphosate (0.41 kg a.i. ha^{-1}) was applied to the SLM and the cereal monoculture plots two weeks before seeding. Plot over-sprays of Pursuit Ultra (0.02 kg a.i. ha^{-1} imazethapyr and 0.19 kg a.i. ha^{-1} sethoxydim) for weed control occurred twice in May 2006 at LAC. Pursuit Ultra was used as an overspray as it has no negative effect on kura clover growth.

Cereals were seeded in Years 1 and 2 according to the rotation sub-plot treatments outlined above. They were seeded at a depth of 2.5 to 4 cm, a rate of 300 seeds m^{-2}, and row spacing of 23 cm. Fertilizer (P_2O_5, K_2O, and S) was applied according to soil test recommendations for barley and triticale (Norwest Labs, Edmonton, AB). Nitrogen fertilizer (46-0-0) was applied according to the nitrogen treatments above; broadcast and incorporated during seeding at ERS, or side-banded during seeding at LAC. Seeding occurred at ERS on 23 May 2006 and 24 May 2007; and at LAC on 29 May 2006 and 31 May 2007. At ERS, cereals were seeded perpendicular to the kura. Cereals were seeded between the kura rows at LAC. A 6-row, zero-till disc drill was used at ERS, and a Conservpak® air seeder at LAC.

Plots were harvested at the soft-dough cereal stage (stage 85) (Zadoks et al. 1974). At ERS, plots were harvested on 8 Aug. 2006 and 2007 for barley; and 21 Aug. 2006 for triticale. At LAC, harvests took place on 15 Aug. 2006 and 2007 for barley; and 29 Aug. 2006 for triticale. Silage yield was taken at ERS from a sample 0.6 x 5.4 m collected with a Swift Current flail mower (Swift Current, SK). A 0.3 m swath was first removed from the front and back of each plot to avoid any 'edge effects'. A Swift Current plot forage harvester (Swift Current, SK) was used at LAC to collect material from the whole plot. Species composition was determined using a 0.5 x 1 m quadrat placed over three cereal rows per plot and kura in the intervening spaces. Plants were clipped by hand and separated into cereal, legume, and non-crop, and species composition was determined from the dry weights of each. Both the machine and hand harvested materials were placed in a forced air dryer for 48 hours at 48 °C, and weighed. Samples from the LAC Year 1 and Year 2 silage material were ground with a Wiley mill to 1 mm and then analyzed for forage nutritive value. Nitrogen was determined using a LECO N-analyzer (Model CN-2000, Leco Corp., St Joesph, MI) and multiplied by 6.25 for crude protein (CP). The acid detergent fibre (ADF) and neutral detergent fibre (NDF) analysis were conducted using batch procedures outlined by ANKOM Technology Corporation (Fairport, NY) for an ANKOM200 Fibre Analyzer (Komarek, 1993; Komarek et al., 1994). Relative feed value (RFV) was calculated from ADF and NDF concentrations using the following equations: (1) Digestible Dry Matter (DDM) = 88.9 – (0.779 x % ADF); (2) Dry Matter Intake (DMI) = 120 / (% NDF); (3) RFV = (DDM x

DMI) / 1.29 (Jeranyama and Garcia, 2004). At ERS, the remaining unharvested biomass was mowed and raked off the plots.

Six weeks after the silage harvest, kura regrowth was measured. A 1 x 1m quadrat was placed in the centre of each living mulch (LM) and suppressed living mulch (SLM) plot. The kura material within that quadrat was hand-clipped to a height of one inch. The harvested regrowth material was then placed in a forced air dryer for 48 hours at 48 °C and weighed. Samples from the LAC Year 1 and Year 2 kura regrowth material were ground with a Wiley mill to 1 mm and then analyzed for forage nutritive value. Nitrogen was determined using a LECO N-analyzer (Model CN-2000, Leco Corp., St Joesph, MI) and multiplied by 6.25 for CP.

Statistical Analysis

An analysis of variance was performed using the PROC MIXED procedure of SAS (Littell et al., 2006) at $P < 0.05$. Nitrogen level, rotation, and their interaction were considered fixed effects in the split plot analysis. Results for species composition, CP, ADF, and NDF were arcsin transformed for analysis according to Steel et al. (1997). Results for RFV were square root transformed for analysis. Significant nitrogen level effects were separated with orthogonal polynomial contrasts, using coefficients derived in the IML procedure of SAS. Significant rotation effects were separated using single degree of freedom contrasts. Sites were analyzed separately due to significant site x rotation interactions. Years within site were analyzed separately due to significant rotation x year interactions.

Results and Discussion

Environmental Conditions

Environmental conditions were generally favorable for growth in Year 1 and Year 2 at Edmonton and Lacombe. Rainfall in Edmonton for May to August was less than the 30-year average (285 mm) in both Years 1 and 2 (Appendix 2). Seasonal (May to August) Edmonton temperatures were slightly above normal, with four-month mean temperatures of 16.5 °C in Year 1 and 15.9 °C in Year 2. Rainfall at Lacombe from May to August in Year 1 (323 mm) and Year 2 (435 mm) was greater than the 30-year average of 279 mm

(Appendix 2). Seasonal temperatures for May to August in Lacombe were slightly above the norm of 13.6 °C for both Years 1 (14.8 °C) and 2 (14.4 °C).

Nitrogen and Rotation Effects

Nitrogen did not alter any traits measured at Edmonton (Table 2-1) or Lacombe (Table 2-2), except for silage yield at Lacombe. Rotation significantly affected all traits, except for kura regrowth yield at Edmonton (Table 2-1) and regrowth crude protein at Lacombe (Table 2-3). At Edmonton, there was a significant nitrogen x rotation interaction for percent cereal. This was largely due to percent cereal values peaking at different nitrogen levels for each rotation. At Lacombe, silage yield was affected by a significant nitrogen x rotation interaction in Year 2. For most rotations, yield increased as nitrogen increased. The significant interaction was the result of the LM + T-B rotation having a lower yield at a nitrogen level other than the low N treatment.

Silage Dry-Matter Yields

At Edmonton, silage dry matter (DM) yields were greater in Year 1 (2.61 to 5.04 tonnes ha^{-1}) than in Year 2 (2.09 to 4.23 tonnes ha^{-1}) (Table 2-4). This is most likely due to the poor cereal emergence and establishment experienced in Year 2 as a result of lower rainfall at the time of seeding. In Year 1, the barley rotation had the highest DM yield. Barley has previously out-yielded triticale when grown for silage at this site (Khorasani et al., unpublished data). The presence of kura in the two living mulch (LM + B-B and LM + T-B) and two suppressed living mulch (SLM + B-B and SLM + T-B) rotations decreased DM yield by 15 to 39% compared to the barley (B-B) and triticale (T-B) monocultures. At Edmonton in Year 2, the LM rotations were essentially kura monocultures, and yielded significantly more than the SLM rotations, as well as the cereal monoculture rotations (4.23 tonnes ha^{-1} vs. 2.09 tonnes ha^{-1} and 2.21 or 2.90 tonnes ha^{-1} respectively). The environmental conditions at the time of cereal seeding were not ideal. The soil was compacted and as a result, cereal emergence was impeded. This led to poor barley and vigorous kura stands.

In Lacombe, silage DM yields ranged from 4.89 to 11.60 tonnes ha^{-1} (Table 2-5), with yields for the six rotation treatments increasing linearly as the nitrogen treatment increased in Year 1. Unlike at Edmonton, the triticale (T-B) rotation yielded significantly more than the barley (B-B) rotation in Year 1. Helm and Salmon (2002) found that, over a two-year period at Lacombe, average triticale yields were over 3 tonnes ha^{-1} greater than barley yields. At Lacombe, Baron et al. (2000) also documented that triticale out-yielded barley by 27%. DM yields of the barley and triticale rotations were generally greater than those of the LM and SLM rotations, with DM yields of LM rotations 15 to 21% lower than the SLM rotations in Year 1. In Year 2, there were no significant yield differences between the LM and SLM rotations.

When comparing the cereal species seeded in the six rotation treatments, the T-B sequence performed the best, both in monoculture and in combination with the kura living mulch at Lacombe. When yields of each rotation are averaged across both years and the nitrogen treatments, the T-B monoculture rotation yield was the highest (9.46 tonnes ha^{-1}), followed by the SLM + T-B rotation (7.84 tonnes ha^{-1}), and the B-B monoculture rotation (7.79 tonnes ha^{-1}). These average yields suggest that rotating the cereal species from triticale to barley provided a yield advantage.

Even with suppression, the presence of the kura resulted in decreased DM yields. Other studies involving seeding cereals with legume living mulches have experienced decreased yields compared to cereal monocultures (Erberlein et al., 1992; Contreras-Govea and Albrecht, 2005). For example, silage DM yields of winter wheat-kura clover living mulches were 1.6 Mg ha^{-1} less than that of sole winter wheat (Contreras-Govea et al., 2006). In order to increase the effectiveness of suppression and avoid significant yield losses, an increased rate of glyphosate may need to be applied before seeding the cereals. According to Affeldt et al. (2004), glyphosate rates up to 1.66 kg a.i. ha^{-1}, greater than the rate applied in this experiment, were required to provide the level of kura control to decrease competition for corn production. Another option would be seeding a cereal variety that is more competitive earlier in the growing season. Winter wheat has been shown to emerge and establish successfully in kura clover (Contreras-Govea and Albrecht, 2005; Contreras-Govea et al., 2006). Fall seeding a winter crop may lead to better cereal establishment and higher silage DM yields in a kura living mulch.

Species Composition

At Edmonton in Year 1, the two SLM rotations had more cereal (2 to 45% vs. 0 to 5% cereal), and less kura, than the two LM rotations (Table 2-6; Appendix 3). Contreras-Govea and Albrecht (2005) also found that kura clover significantly decreased the amount of cereal contributing to yield when the cereal was seeded into kura clover.

At Lacombe, the SLM + B-B rotation had a higher percentage of cereal (46 to 75%) and a lower percentage of kura than the LM + B-B rotation (6 to 53% cereal) over both years (Table 2-7; Appendix 4). While there was no significant difference in either the percentage of cereal or kura between the LM + T-B and SLM + T-B rotations in Year 1, there were in Year 2 (20 % cereal vs. 56%, respectively). The LM + T-B and SLM + T-B rotations tended to have higher percentages of cereal than the LM + B-B and SLM + B-B rotations at Lacombe over the two years. This is further evidence that the T-B cereal sequence is superior to the barley monoculture (B-B) sequence.

Even with herbicide suppression in the SLM rotations, kura still represented 49% to 97% of DM yield at Edmonton, and 24% to 54% of DM yield at Lacombe. The percentage of yield composed of kura also increased significantly from Year 1 to Year 2 in the LM and SLM rotations at both Edmonton and Lacombe. Laberge et al. (2005) found that the proportion of kura clover increased from 18% of yield in the first year to 45% in the second when grown with grasses in a pasture. Kura is able to spread via rhizomes (Sheaffer and Marten, 1991) and once established, will soon out-compete companion plants (Laberge et al., 2005). The increasing spread and competitive ability of kura with time suggest that an increased level of suppression may be necessary in later years.

Forage Quality

Forage quality of all six rotation treatments at Lacombe was average to excellent (Table 2-8). Crude protein (CP) levels were significantly higher in the barley (B-B) rotation than the triticale (T-B) rotation in Year 1. There was no difference in CP between the cereal monocultures and LM or SLM rotations (ranged from 10 to 13% CP). In Year 2, CP levels were higher in the LM and SLM rotations than in the cereal monocultures (13 to 15% vs. 11 % CP, respectively). Kura clover has reported CP levels ranging from 17.4 to

23.4% (Sheaffer and Marten, 1991; Sleugh et al., 2000), while barley and triticale silage typically has CP levels of 9.4 to 13.6% (Baron et al., 1999; Baron et al., 2000). The addition of the protein-rich kura material increased the CP levels of silage from the LM and the SLM rotations above that of the cereal monocultures. Zemenchik et al. (2002) found that adding kura clover to grass pastures increased CP concentrations compared to the grass monocultures. Mixtures of kura clover with oats, barley, and winter wheat also had greater CP levels than the respective cereal monocultures (Contreras-Govea and Albrecht, 2005).

Acid detergent fibre (ADF) and neutral detergent fibre (NDF) values tend to be lower in legumes than in cereals. Kura clover silage has previously reported ADF values ranging from 17.0 to 25.2% and NDF values of 22.1 to 30.6% (Contreras-Govea et al., 2006). These values are lower than those documented in other trials for both barley and triticale silage (Baron et al., 1999; Baron et al., 2000). In this experiment, the ADF and NDF levels were the lowest in the LM and SLM rotations compared to the B-B and T-B rotations (Table 2-8). Contreras-Govea et al. (2006) found that the addition of kura clover to winter wheat silage decreased the ADF and NDF levels compared to winter wheat monocultures. The NDF levels of the harvested material from the LM and SLM rotations were lower in Year 2 than in Year 1. This was likely due to the increased percentage of kura in those treatments in Year 2.

The relative feed values (RFV) for the LM and the SLM rotations were greater than for the cereal monoculture rotations (B-B and T-B) (Table 2-8). RFV values are based on the digestible dry matter intake of alfalfa at 41% ADF and 53% NDF, giving a RFV of 100 (Jeranyama and Garcia, 2004). High-producing dairy cows should consume forage with an RFV of 125 or more, with the ideal RFV being 150 (Amaral-Phillips et al., 2001). The addition of the kura in the LM and SLM rotations resulted in RFV's of 125 to 158, compared to the RFV's of 99 to 119 for the cereal monoculture rotations (B-B and T-B). Silage from the LM and SLM rotations would be suitable for inclusion in rations for dairy cattle. It is well documented that mixtures of kura clover and grasses or small grains have higher forage quality than grass or cereal monocultures (Sleugh et al., 2000; Zemenchik et al., 2002; Contreras-Govea and Albrecht, 2005).

Kura Clover Regrowth and Crude Protein

Kura clover regrew following the silage harvest at Edmonton in both years, with yields ranging from 0.73 to 1.34 tonnes ha^{-1} (Table 2-9). In Year 1, the LM + B-B rotation had more regrowth than the SLM + B-B rotation, indicating that suppression combined with higher percentage of cereal negatively affected kura growth. At Lacombe, regrowth ranged from 0.44 to 1.38 tonnes ha^{-1} (Table 2-9). While there were no significant differences between regrowth in Year 1, the LM + B-B rotation produced more regrowth biomass than the SLM + B-B rotation in Year 2.

Walker (2002) examined the effects of harvest frequency on regrowth in pure stands of kura clover at Edmonton. She observed regrowth yields ranging from 0.50 to just over 3.00 tonnes ha^{-1} for late season harvests. However, these regrowth yields are lower than those observed in other trials. Peterson et al. (1994) clipped kura clover three to six times in a season to simulate a grazing regime for sheep at St. Paul, Minnesota. They obtained yields ranging from 1.00 to 3.00 tonnes ha^{-1} for four to six weeks of regrowth, depending on the year. Seguin et al. (2000) harvested kura clover stands four times per season at both Becker and Rosemount, Minnesota, and documented kura regrowth yields ranging from 1.00 to 3.50 tonnes kg ha^{-1}. The lower regrowth yields in this experiment could be the result of competition from the cereals and the cooler growing environment.

Crude protein levels of the kura regrowth material ranged from 17 to 25% at Lacombe and were not significantly different among the LM and SLM rotations (Table 2-10). The CP values obtained in our experiment generally agree with those found in the literature (Sheaffer and Marten, 1991; Sleugh et al., 2000). Based on previously documented ADF and NDF values for kura clover from Contreras-Govea et al. (2006), projected RFV's for this regrowth material would range from 210 to 293. This is well above the suggested RFV of 150 for feed for high-producing dairy cattle (Amaral-Phillips et al., 2001). However, feeding a ration of 100% kura clover could lead to digestion difficulties, such as bloat (Majak et al., 2003). The kura regrowth could be used to mix with lower quality material feed. When straw is fed during the winter, it is often supplemented with materials that have lower fibre contents and higher CP values, such as grain or canola meal (Suleiman, 1990). The kura regrowth material could replace these expensive protein supplements.

Conclusion

Kura clover living mulch systems have the potential to be adopted for cereal silage production in central Alberta. Suppressed living mulches (SLM) were preferable to non-suppressed mulches (LM). The SLM rotations tended to have higher silage DM yields and higher percentages of cereal in the mixture, than the LM rotations. Forage quality of the SLM rotations was lower than that of the LM rotations, but was still adequate for lactating dairy cows and higher quality than silage from the cereal monoculture rotations (B-B and T-B). The suppression used in the SLM rotations was inadequate, particularly in Edmonton. To better control early season competition from the kura living mulch, a more effective method of suppression should be used. For example, increasing the rate of glyphosate applied, or a combination of mechanical and chemical suppression.

At Lacombe, the T-B cereal sequence seemed preferable to the B-B sequence. Silage DM yields and cereal proportions tended to be greater over the two years in the LM + T-B and SLM + T-B rotations than in the LM + B-B and SLM + B-B rotations. While forage quality was comparable between the B-B and T-B rotations, the higher yields achieved with triticale in Year 1 would make the T-B cereal sequence more desirable to producers.

Varying the soil nitrogen level did not significantly affect most of the traits measured at Edmonton and Lacombe. The soils in Edmonton had inherently high nitrogen levels (90 kg N ha^{-1}) before the application of any fertilizer. With the lowest N treatment at 90 kg N ha^{-1}, the medium (150 kg N ha^{-1}) and high nitrogen (225 kg N ha^{-1}) treatments were even greater in order to create distinct differences. These same high rates of N had to be adopted at Lacombe. Unfortunately, these high soil N rates likely reduced the kura clover's biological nitrogen fixation. Repeating the experiment on soils with lower N levels would allow the effect of the kura on soil N to be better understood.

Kura clover living mulches could be utilized in Alberta to increase the sustainability of current cereal silage production systems. Our research suggests that a suitable target silage species composition would be approximately 60% cereal and 40%

kura, as seen in the SLM + T-B rotation in Year 2. With this species mix, yield reductions

of 136, making it suitable for lactating dairy cattle. More comparisons of different cereal to kura ratios are needed, however, to more accurately gauge the ideal silage species composition. Further research is required to examine the competition dynamics between the kura living mulch and cereal species, and the optimal soil nitrogen level to maximize yields and take advantage of the clover's nitrogen fixing abilities. The potential benefits of a kura clover living mulch, such as weed control, disease reduction, and nitrogen benefits, need to be investigated in order to determine if they out-weigh the yield reductions documented here.

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Table 2-1. Nitrogen (main plot), Rotation (subplot), and Interaction Effects at the University of Alberta Edmonton Research Station (ERS) for Silage Yield, Species Composition, and Regrowth Yield in Year 1 (2006) and Year 2 (2007).

	Silage Yield		Percent Cereal		Percent Kura		Regrowth Yield	
Effect	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Nitrogen (N) F test (df=2)	NS	NS	NS	NS	NS	NS	NS	NS
Rotation (R) F test (df=5)	***	***	***	***	***	*	***	NS
N x R F test (df=17)	NS	NS	*	**	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 2-2. Nitrogen (main plot), Rotation (subplot), and Interaction Effects at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) for Silage Yield, Species Composition, and Regrowth Yield in Year 1 (2006) and Year 2 (2007).

	Silage Yield		Percent Cereal		Percent Kura		Regrowth Yield	
Effect	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Nitrogen (N) F test (df=2)	*	*	NS	NS	NS	NS	NS	NS
Rotation (R) F test (df=5)	***	***	***	***	**	***	***	*
N x R F test (df=17)	NS	*	NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 2-3. Nitrogen (main plot), Rotation (subplot), and Interaction Effects at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) for Silage Crude Protein (CP), Acid Detergent Fibre (ADF), Neutral Detergent Fibre (NDF), Relative Feed Value (RFV), and Kura Regrowth Crude Protein (CP) in Year 1 (2006) and Year 2 (2007).

	CP		ADF		NDF		RFV		Regrowth CP	
Effect	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Nitrogen (N) F test (df=2)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rotation (R) F test (df=5)	**	***	***	**	**	***	***	***	NS	NS
N x R F test (df=17)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 2-4. Silage Dry Matter (DM) Yield (tonnes ha^{-1}) for Six Rotations at the University of Alberta Edmonton Research Station (ERS) in Year 1 (2006) and Year 2 (2007).

Rotation[‡]	Silage Dry Matter Yield	
	Year 1 (barley or triticale)	Year 2 (barley)
	------------------- tonnes ha^{-1}	-------------------
B-B	5.04	2.90
T-B	3.28	2.21
LM + B-B	3.10	4.23
LM + T-B	2.79	4.23
SLM + B-B	3.15	2.09
SLM + T-B	2.61	2.09
SE nitrogen	0.16	0.28
SE rotation	0.23	0.40
CONTRASTS		
B-B vs. T-B	***	NS
B-B vs. (LM + B-B) and (SLM + B-B)	***	NS
(LM + B-B) vs. (SLM + B-B)	NS	***
T-B vs. (LM + T-B) and (SLM + T-B)	**	*
(LM + T-B) vs. (SLM + T-B)	NS	***

[‡] Rotation Treatments are as follows: 1) B-B: barley in Years 1 and 2; 2) T-B: triticale in Year 1, barley in Year 2; 3) LM + B-B: kura living mulch plus barley in Years 1 and 2; 4) LM + T-B: kura living mulch plus triticale in Year 1, kura living mulch plus barley in Year 2; 5) SLM + B-B: suppressed kura living mulch plus barley in Years 1 and 2; 6) SLM + T-B: suppressed kura living mulch plus triticale in Year 1, suppressed kura living mulch plus barley in Year 2.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means.

Table 2-5. Silage Dry Matter (DM) Yield (tonnes ha^{-1}) for Three Nitrogen Treatments and Six Rotations at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

Nitrogen Treatment	Rotation	Silage Dry Matter Yield Year 1 (barley or triticale)	 Year 2 (barley)
		------- tonnes ha^{-1}	-------
Low Nitrogen	B-B	7.50	5.75
	T-B	10.01	6.28
	LM + B-B	4.89	5.83
	LM + T-B	5.86	6.40
	SLM + B-B	5.63	5.07
	SLM + T-B	8.72	5.33
Medium Nitrogen	B-B	8.86	7.65
	T-B	11.60	8.46
	LM + B-B	6.11	6.22
	LM + T-B	7.33	5.25
	SLM + B-B	7.69	6.00
	SLM + T-B	9.68	6.36
High Nitrogen	B-B	7.99	8.97
	T-B	10.60	9.70
	LM + B-B	7.09	6.60
	LM + T-B	9.17	6.94
	SLM + B-B	7.92	6.36
	SLM + T-B	9.80	7.15
SE nitrogen		0.61	0.49
SE rotation		0.44	0.40
N linear		*	**
N quadratic		NS	NS
CONTRASTS			
B-B vs. T-B		***	NS
B-B vs. (LM + B-B) and (SLM+ B-B)		***	***
(LM +B-B) vs. (SLM + B-B)		*	NS
T-B vs. (LM + T-B) and (SLM + T-B)		***	***
(LM + T-B) vs. (SLM + T-B)		***	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means.

Table 2-6 Species Composition of Silage Dry Matter Yield for the Three Nitrogen Level Treatments and Six Rotations at the University of Alberta Edmonton Research Station (ERS) in Year 1 (2006) and Year 2 (2007).

Nitrogen Treatment	Rotation	Percent Cereal		Percent Kura	
		Year 1 (barley or triticale)	Year 2 (barley)	Year 1	Year 2
		%			
Low Nitrogen	B-B	97 (1.39)[†]	25 (0.50)	.	.
	T-B	86 (1.19)	37 (0.62)	.	.
	LM + B-B	0 (0.03)	0 (0.00)	93 (1.34)[†]	95 (1.37)
	LM + T-B	0 (0.05)	0 (0.00)	95 (1.37)	99 (1.50)
	SLM + B-B	3 (0.71)	0 (0.04)	49 (0.78)	96 (1.43)
	SLM + T-B	9 (0.25)	0 (0.03)	87 (1.23)	91 (1.29)
Medium Nitrogen	B-B	90 (1.27)	66 (0.95)	.	.
	T-B	89 (1.23)	57 (0.86)	.	.
	LM + B-B	5 (0.19)	0 (0.00)	81 (1.12)	95 (1.43)
	LM + T-B	1 (0.05)	0 (0.00)	88 (1.26)	99 (1.50)
	SLM + B-B	45 (0.74)	2 (0.10)	52 (0.80)	97 (1.44)
	SLM + T-B	30 (0.56)	3 (0.11)	65 (0.94)	86 (1.24)
High Nitrogen	B-B	88 (1.25)	69 (1.00)	.	.
	T-B	61 (0.93)	15 (0.37)	.	.
	LM + B-B	0 (0.03)	0 (0.00)	93 (1.38)	98 (1.47)
	LM + T-B	1 (0.08)	0 (0.00)	95 (1.35)	97 (1.46)
	SLM + B-B	34 (0.60)	6 (0.18)	65 (0.96)	94 (1.39)
	SLM + T-B	37 (0.65)	4 (0.11)	63 (0.92)	89 (1.28)
SE nitrogen		(0.05)	(0.06)	(0.08)	(0.06)
SE rotation		(0.07)	(0.06)	(0.06)	(0.07)
CONTRASTS					
B-B vs. T-B		*	**	.	.
B-B vs. (LM + B-B) and (SLM + B-B)		***	***	.	.
(LM + B-B) vs. (SLM + B-B)		***	NS	***	NS
T-B vs. (LM + T-B) and (SLM + T-B)		***	***	.	.
(LM + T-B) vs. (SLM + T-B)		***	NS	***	**

[†] Percentage of yield data was transformed to the arcsin (square root of x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means from the transformed data.

. Data not collected from the plot.

Table 2-7. Species Composition of Silage Dry Matter Yield for the Six Rotation at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

	Percent Cereal		Percent Kura	
Rotation	Year 1 (barley or triticale)	Year 2 (barley)	Year 1	Year 2
	%			
B-B	99 (1.54)[†]	94 (1.42)	.	.
T-B	98 (1.51)	96 (1.51)	.	.
LM + B-B	53 (0.81)	6 (0.15)	47 (0.76)[†]	93 (1.38)
LM + T-B	63 (0.92)	20 (0.35)	37 (0.65)	80 (1.22)
SLM + B-B	75 (1.08)	46 (0.71)	24 (0.49)	54 (0.86)
SLM + T-B	74 (1.05)	56 (0.84)	26 (0.52)	42 (0.72)
SE nitrogen	(0.06)	(0.11)	(0.08)	(0.15)
SE rotation	(0.07)	(0.01)	(0.08)	(0.11)
CONTRASTS				
B-B vs. T-B	NS	NS	.	.
B-B vs. (LM + B-B)and (SLM+ B-B)	***	***	.	.
(LM +B-B) vs. (SLM + B-B)	***	***	**	***
T-B vs. (LM + T-B) and (SLM + T-B)	***	***	.	.
(LM + T-B) vs. (SLM + T-B)	NS	***	NS	***

[†] Percentage of yield data was transformed to the arcsin (square root of x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means from the transformed data.

. Data not collected from the plot.

Table 2-8. Crude Protein (CP), Acid Detergent Fibre (ADF), Neutral Detergent Fibre (NDF), and Relative Feed Value (RFV) of Silage Harvested at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

Rotation	Year 1 (barley or triticale)				Year 2 (barley)			
	CP	ADF	NDF	RFV	CP	ADF	NDF	RFV
				%				
B-B	12 (1.35)[†]	27 (0.55)[†]	53 (0.82)[†]	119(1.09)[‡]	11 (0.34)	32 (0.61)	60 (0.89)	99 (0.99)
T-B	10 (0.32)	30 (0.57)	56 (0.85)	110 (1.05)	11 (0.34)	32 (0.60)	57 (0.86)	104 (1.02)
LM + B-B	13 (0.37)	24 (0.52)	44 (0.73)	148 (1.22)	15 (0.40)	28 (0.56)	40 (0.69)	155 (1.24)
LM + T-B	11 (0.34)	28 (0.56)	50 (0.79)	125 (1.12)	15 (0.40)	28 (0.55)	40 (0.67)	158 (1.25)
SLM + B-B	12 (0.35)	24 (0.52)	46 (0.75)	141 (1.19)	14 (0.39)	29 (0.57)	44 (0.72)	143 (1.20)
SLM + T-B	10 (0.32)	28 (0.56)	50 (0.79)	124 (1.11)	13 (0.37)	29 (0.57)	46 (0.74)	136 (1.17)
SE nitrogen	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.03)
SE rotation	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.04)
CONTRASTS								
B-B vs. T-B	*	**	NS	NS	NS	NS	NS	NS
B-B vs. (LM + B-B) and (SLM + B-B)	NS	***	***	***	***	**	***	***
(LM + B-B) vs. (SLM + B-B)	NS	NS	NS	NS	NS	NS	NS	NS
T-B vs. (LM + T-B) and (SLM + T-B)	NS	NS	***	**	**	**	***	***
(LM + T-B) vs. (SLM + T-B)	NS	NS	NS	NS	*	NS	*	*

[†] CP, ADF, and NDF were transformed to the arcsin (square root x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.
[‡] RFV was transformed to the square root (x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.
*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS Not significant at the 0.05 probability level.
SE standard error of the difference of two least-squares means from the transformed data.

Table 2-9. Kura Clover Regrowth Yield (tonnes ha^{-1}) for Six Rotations at the University of Alberta Edmonton Research Station (ERS) and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) collected Six Weeks After Silage Harvest in Year 1 (2006) and Year 2 (2007).

	Kura Clover Regrowth Yield			
	ERS		LAC	
Rotation	Year 1	Year 2	Year 1	Year 2
	tonnes ha^{-1}			
B-B	.	.	.	.
T-B	.	.	.	.
LM + B-B	1.34	0.85	1.38	1.20
LM + T-B	0.85	0.82	0.45	1.14
SLM + B-B	1.21	0.88	1.29	0.96
SLM + T-B	0.75	0.73	0.44	0.93
SE nitrogen	0.08	0.15	0.09	0.15
SE rotation	0.07	0.07	0.07	0.11
CONTRASTS				
(LM + B-B) vs. (SLM + B-B)	*	-	NS	*
(LM + T-B) vs. (SLM + T-B)	NS	-	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.
SE standard error of the difference of two least-squares means.
. Data not collected from the plot.
- Contrast not performed due to no significant rotation effect.

Table 2-10. Crude Protein (CP) Content for Kura Clover Regrowth from Six Rotations at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

	CP of Kura Clover Regrowth			
Rotation	Year 1		Year 2	
	%			
B-B	.		.	
T-B	.		.	
LM + B-B	18	(0.44)[†]	25	(0.52)
LM + T-B	17	(0.43)	25	(0.53)
SLM + B-B	19	(0.45)	25	(0.52)
SLM + T-B	22	(0.48)	25	(0.52)
SE nitrogen	(0.04)		(0.01)	
SE rotation	(0.04)		(0.01)	

[†] Percent CP was transformed to the arcsin (square root of x) for analysis and transformed lsmeans are presented in brackets behind original lsmeans.

SE standard error of the difference of two least-squares means from the transformed data.

. Data not collected from these plots.

Chapter Three: Factors Influencing Intercropping Dynamics

Null Hypotheses

Barley grown following barley will not be significantly different from barley grown following triticale at the same soil nitrogen level for emergence, height, incident light available, and root weights.

Cereals grown alone will not be significantly different from cereals grown with kura clover living mulches at the same soil nitrogen level for emergence, height, incident light available, and root weights.

Cereals grown with a suppressed kura clover living mulch will not be significantly different from cereals grown with a non-suppressed kura clover living mulch at the same soil nitrogen level for emergence, height, incident light available, and root weights.

Early season ground cover, canopy heights, and incident light available will not be significantly different between non-suppressed and suppressed kura clover living mulches.

Introduction

Interest in adapting cereal-legume intercropping to the mechanized crop production of North America is increasing (Vandermeer, 1989; Liebman, 1995). Benefits of intercropping include: enhanced yields (Berkenkamp and Meeres, 1987; Fujita et al., 1992), improved forage quality (Wall et al., 1991; Anil et al., 1998), weed suppression (Hartl, 1989; Izaurralde et al., 1993), and nitrogen inputs (Izaurralde et al., 1993; Ghaffarzadeh, 1997). Intercropping a cereal and legume allows the producer to take advantage of the nitrogen contributed to the system by the legume, and decrease the amount of nitrogen fertilizer applied (Rao, 1986; Ofori and Stern, 1987).

One form of cereal-legume intercropping, called a living mulch, has shown promise as an alternative method for crop production. A living mulch is formed when an annual crop, such as a cereal, is seeded into an established legume cover crop (Altieri, 1995; Hartwig and Ammon, 2002). Living mulches, utilizing a variety of forage legumes, have been studied for use in corn (*Zea mays* L.) production systems in North America (Vrabel, 1983; Ebelhar et al., 1984; Scott et al., 1987; Echtenkamp and Moomaw, 1989; Leary and DeFrank, 2000; Zemenchik et al., 2000). According to Wall et al. (1991), the red clover (*Trifolium pratense* L.) in a corn-red clover living mulch system decreased soil losses due to erosion and increased silage yields compared to the conventionally grown, unfertilized corn monoculture. Jones and Clements (1993) seeded two successive winter wheat (*Triticum aestivum* L.) crops into a living mulch of white clover and harvested them for grain. The white clover did not interfere with combining and increased the grain yield of the second crop by 25% (Jones and Clements, 1993).

Kura clover (*Trifolium ambiguum* M. Bieb.) has shown promise as a living mulch for cereal silage production (Zemenchik et al., 1998; Contreras-Govea et al., 2006). Kura clover is a long-lived perennial legume (Sheaffer and Marten, 1991). It is well-adapted to a variety of soil and climatic conditions, in addition to being both drought and cold tolerant (Speer and Allison, 1985; Moore, 2003). Kura is strongly rhizomatous (Forde et al., 1989), but often slow to establish (Seguin et al., 1999). A potential limitation with using a kura clover living mulch system for cereal production is competition between the two crops. A vigorous annual cereal, such as barley (*Hordeum vulgare* L.), could shade the living mulch, reducing its growth (Hay and Hunt, 1989; Sheaffer, 1989). This could diminish the benefits of the living mulch. Below-ground competition could also be a factor. Being a perennial, kura clover will have a well developed root system the spring following establishment. An annual cereal crop seeded into this established clover could be at a disadvantage when accessing soil nutrients and water.

Little information is available on the intercropping dynamics between a kura clover living mulch and cereals during the growing season. Most of the studies have focussed on yield and forage quality. The objective of this experiment was to assess the compatibility of a kura clover living mulch with barley or triticale (X *Triticosecale wittmack*) for silage production in central Alberta. The effects of non-suppressed and suppressed kura clover living mulches on barley and triticale emergence, light interception, height, and root growth were examined.

Materials and Methods

Treatments and Measurements

Field experiments were conducted at the University of Alberta Research Station (ERS) in Edmonton, Alberta and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC), Alberta over two years; Year 1 (2006) and Year 2 (2007). Plots at ERS and LAC were established on black chernozemic soils. Soil pH at the test sites ranged from 6.3 to 7.3. 'Cossack' kura clover plots were established in June 2005 at ERS with a 4-row disc drill, and at LAC with a Conservpak® air seeder (Conserva Pak Seeding Systems, Indian Head, SK). Kura seeding rate was 12 kg ha^{-1}, depth was 1.5 to 2 cm, and row spacing was 30 cm at ERS and 23 cm at LAC. Kura seed was inoculated with a commercially available mixture of *Rhizobium leguminosarum* biovar *trifolii* strains prior to sowing. 'Seebe barley' and 'AC Morgan' oats (*Avena sativa* L.) were seeded at a rate of 300 seeds m^{-2} and row spacing of 23 cm into designated 'kura-free' plots in order to establish the continuous barley and the rotational cereal rotation treatments. Soil P, K, and S levels were maintained based on soil test recommendations (Norwest Labs, Edmonton, AB). ERS plots were hand-weeded. In September 2005, both sites were mowed with a sickle mower and the plant material raked off the plots.

The experiment was arranged in a split-plot, randomized complete block design with four replications per site. Sub-plot dimensions were 2.76 x 6 m at ERS and 3.66 x

7.62 m at LAC. Nitrogen was the main plot treatment and rotation was the sub-plot treatment. The three nitrogen (N) application treatments were: (1) low soil N (90 kg N ha^{-1} in Year 1 and 11 to 76 kg N ha^{-1} in Year 2); (2) medium soil N (150 kg N ha^{-1} in Year 1 and 93 to 150 kg N ha^{-1} in Year 2); and (3) high soil N (225 kg N ha^{-1} in Year 1 and 176 to 225 kg N ha^{-1} in Year 2). The six rotation treatments included: (1) B-B (barley in Years 1 and 2); (2) T-B (triticale in Year 1 and barley in Year 2); (3) LM + B-B (kura clover living mulch plus barley in Years 1 and 2); (4) LM + T-B (kura living mulch plus triticale in Year 1 and kura living mulch plus barley in Year 2); (5) SLM + B-B (suppressed kura living mulch plus barley in Years 1 and 2); and (6) SLM + T-B (suppressed kura living mulch plus triticale in Year 1 and suppressed kura living mulch plus barley in Year 2). Glyphosate (0.41 kg a.i. ha^{-1}) was applied to the SLM and the cereal monoculture plots two weeks before seeding. Plot over-sprays of Pursuit Ultra (0.02 kg a.i. ha^{-1} imazethapyr and 0.19 kg a.i. ha^{-1} sethoxydim) for weed control occurred twice in May 2006 at LAC. Pursuit Ultra was used as an overspray as it has no negative effect on kura clover growth.

Cereals were seeded in Years 1 and 2 according to the rotation sub-plot treatments outlined above. They were seeded at a depth of 2.5 to 4 cm, a rate of 300 seeds m^{-2}, and row spacing of 23 cm. Fertilizer (P_2O_5, K_2O, and S) was applied according to soil test recommendations for barley and triticale (Norwest Labs, Edmonton, AB). Nitrogen fertilizer (46-0-0) was applied according to the nitrogen treatments above; broadcast and incorporated during seeding at ERS, or side-banded during seeding at LAC. Seeding occurred at ERS on 23 May 2006 and 24 May 2007; and at LAC on 29 May 2006 and 31 May 2007. At ERS, cereals were seeded perpendicular to the kura. Cereals were seeded between the kura rows at LAC. A 6-row, zero-till disc drill was used at ERS, and a Conservpak air seeder at LAC.

Competition from the kura in the LM and SLM treatments at seeding was measured ten days after the suppression treatment. Percent ground cover was visually estimated by placing a 0.5 x 0.5 m quadrat in four locations per plot. Kura canopy height was also recorded. Cereal emergence was recorded two to three weeks after seeding. Light transmittance readings were taken in plots in the high N treatment at 28, 43, 57, and 76 days after cereal planting (DAP). At approximately solar noon, measurements were taken at the top of the cereal canopy and at the top of the kura canopy using a 1 m long

Li-Cor Inc. LI-188B Line Quantum Sensor (Li-Cor, Lincoln, NE, USA). Light levels at the top of each canopy were expressed as a percentage of incident sunlight available. Heights of the cereal and kura canopies were also recorded.

Plots were harvested at the soft-dough cereal stage (stage 85) (Zadoks et al. 1974). At ERS, plots were harvested on 8 Aug. 2006 and 2007 for barley; and 21 Aug. 2006 for triticale. At LAC, harvests took place on 15 Aug. 2006 and 2007 for barley; and 29 Aug. 2006 for triticale. Barley roots were collected two weeks after harvesting in LAC. They were collected from all plants along a 1 m length of row in two spots per plot and were removed to a depth of approximately 10 cm. The roots were then cleaned, dried, and weighed.

Statistical Analysis

An analysis of variance was performed using the PROC MIXED procedure of SAS (Littell et al., 2006) at $P < 0.05$. Nitrogen level, rotation, and their interaction were considered fixed effects in the split plot analysis for all measurements except percent incident light available and the corresponding canopy heights. Days after planting (DAP), rotation, and their interaction were considered fixed for percent incident light available and canopy heights. These repeated measures were modeled using the PROC MIXED statement in SAS with the SP(POW) variance structure according to Littell et al. (2006). Results for kura ground cover and percent incident light available were arcsin transformed for analysis according to Steel et al. (1997). Significant nitrogen level and DAP effects were separated with orthogonal polynomial contrasts, using coefficients derived in the IML procedure of SAS. Significant rotation effects were separated using preplanned contrasts. Sites were analyzed separately due to significant site x rotation interactions. Years within site were analyzed separately due to significant rotation x year interactions.

Results and Discussion

Nitrogen and Rotation Effects

Nitrogen level did not significantly affect any traits measured at Edmonton or Lacombe in either year (Table 3-1; Table 3-2). Rotation significantly affected kura ground cover, early season kura canopy heights, and cereal emergence at both sites, as well as barley root weights in Lacombe. Days after planting (DAP) had a significant effect on all light and height traits except for incident light available to the cereal canopy in Lacombe (Table 3-3; Table 3-4). Rotation was significant for all light and height traits as well, except kura canopy height in Year 1, incident light available to the cereal canopy at Lacombe, and incident light available to the kura canopy at Lacombe in Year 1. The DAP x rotation interaction was not significant for incident light available to the kura canopy at Edmonton in Year 2 and Lacombe in Year 1, incident light available to the cereal canopy at Lacombe in Years 1 and 2, or kura canopy height at Lacombe in Year 2.

Early Season Kura Clover Cover and Canopy Height

In Edmonton, kura clover ground cover ranged from 57 to 100% (Table 3-5; Appendix 5). More ground was covered by the kura living mulches in the living mulch (LM + B-B and LM + T-B) rotations than in the suppressed living mulch (SLM + B-B and SLM + T-B) rotations. Scott et al. (1987) recorded red clover ground covers of 28 and 75% over two years of production. Wall et al. (1991) found that red clover intercropped with corn only covered between 3 and 81% of the ground, depending on the time of year. At Lacombe, there were no differences in ground cover between the LM and the SLM rotations (27 to 35%) in Year 1, but there were in Year 2 with kura covering more ground in the LM rotations than in the SLM rotations (95 and 84% vs. 82 and 67%) (Table 3-5). Although the application of glyphosate (0.41 kg ai ha^{-1}) did negatively impact kura growth, the kura still covered a substantial portion of the ground. Roundup Weathermax was applied at half the recommended rate for in-crop applications, which could account for the low level of kura suppression. Zemenchik et al. (1998) applied glyphosate at a rate more than double that used in our experiment to an established bed of kura before seeding corn into it. That resulted in greater kura suppression than we achieved.

Kura canopy heights at Edmonton ranged from 10 to 18 cm. The kura canopy was taller in the LM rotations than in the SLM rotations at Edmonton in both years (Table 3-5). Canopy heights in Lacombe ranged from 8 to 13 cm. In Year 1, heights were not significantly different between the LM and SLM rotations. In Year 2, heights were greater in the two LM rotations than in the two SLM rotations. Kura canopy heights increased in each LM and SLM rotation from Year 1 to Year 2 in both Edmonton and Lacombe. Kura experiences vigorous early season production (Bryant, 1974), and it's well developed root and rhizome system allows it to spread rapidly and survive harsh winters (Laberge et al., 2005a). These characteristics give kura clover the ability to increase biomass production as the stand ages (Laberge et al., 2005b).

Cereal Emergence

Cereal emergence was lower than the target plant population of 300 plants m^{-2}, which is recommended for maximizing barley and triticale silage production in central Alberta (Salmon et al., 2001).

At Edmonton, barley and triticale emergence was greater in the cereal monoculture rotations (100 to 241 plants m^{-2}) than in the living mulch (LM) and suppressed living mulch (SLM) rotations over Years 1 and 2 (Table 3-6). Emergence was also greater for barley in the SLM rotations (62 to 201 plants m^{-2}) than the LM rotations (35 to 165 plants m^{-2}) in both Year 1 and Year 2. Barley emergence was severely reduced in Year 2 compared to Year 1 at this site. The environmental conditions at the time of seeding in Year 2 at Edmonton were not ideal. The soil was dry and compacted, making it difficult to ensure optimal seed to soil contact. In addition, only 3 mm of rainfall had fallen since 6 May 2007, making for extremely dry conditions. In the two weeks following seeding, it only rained 1.5 mm. These drought-like conditions, combined with the increased kura ground cover, likely contributed to the decrease in cereal emergence in Year 2.

At Lacombe in Year 1 and Year 2, cereal emergence was greater in the cereal monocultures (167 to 201 plants m^{-2}) than in the living mulch (80 to 171 plants m^{-2}) and suppressed living mulch (117 to 192 plants m^{-2}) rotations (Table 3-6). It appears that the kura acted as a barrier to barley and triticale emergence in the LM and SLM rotations. Dabney et al. (1996) observed that the presence of legume material on the soil surface reduced sorghum (*Sorghum bicolor* L.) seedling growth and stand density. The presence of crimson clover (*Trifolium incarnatum* L.) caused a 20% reduction in the number of cotton (*Gossypium hirsutum* L.) seedlings compared to cotton monocultures (Touchton et al., 1984).

At both sites, the SLM rotations had significantly higher barley emergence in Year 2 compared to the LM rotations. These results indicate that herbicide suppression significantly affected cereal emergence. Affeldt et al. (2004) found that herbicide suppression of established kura clover was necessary in order to avoid corn yield losses. In a corn-alfalfa (*Medicago sativa* L.) living mulch system, corn plant counts were 57 to 65% lower in unsuppressed than in suppressed alfalfa plots (Eberlein et al., 1992).

Canopy Heights and Incident Light Available

At Edmonton in Year 1, the cereal canopy was above that of the kura in all rotations except for the LM + T-B rotation (Figure 3-1). When the barley and triticale canopies were above the kura canopy, 100% of the incident light was available for interception by the cereal plants. In the LM + B-B rotation, the barley stand was thin due to poor emergence. As a result, there was little shading of the kura and its canopy received 100% of the incident light available. In the two SLM rotations, the kura canopies received between 75 and 100% of the incident light available. The barley and triticale plants were taller and intercepted more of the incident light available when the kura living mulch had been suppressed with a herbicide in the SLM rotations than in the LM rotations.

At Edmonton in Year 2, the barley canopy was below that of the kura in both LM rotations (Figure 3-2). This resulted in those barley canopies receiving less than 40%, and the kura canopies 100%, of the incident light available during the growing season. The barley in the SLM + B-B and SLM + T-B rotations did not get above the kura canopies until at least 43 days after planting (DAP), which would have negatively impacted its early season growth. Once the barley plants were above the kura canopy, they received 100% of the incident light available. The kura canopies received between 90 and 100% of the incident light available in those two SLM rotations throughout the growing season as a result of the poor barley emergence and increasing kura competitiveness.

At Lacombe, the cereal canopies exceeded the height of the kura canopies in all LM and SLM rotations, except in the LM rotations in Year 2 (Figure 3-3; Figure 3-4). This resulted in 100% of the incident light available being received by the cereal plants.

The amount of incident light available to the kura canopies in the LM and SLM rotations decreased as the season progressed. Clovers tend to be at their most competitive for light and other resources early in the season (Thorsted et al., 2002). This could explain why the cereal canopy was below that of the kura at the first two sampling dates in the LM rotations. The differences in incident light available to the cereal canopies between the LM and SLM rotations could be one factor contributing to the yield differences observed in Chapter 2. For example, the SLM + T-B rotation had higher yields than the LM + T-B rotation in all three N treatments. The cereal canopy was above that of the kura in the SLM + T-B rotation throughout the growing season, while the cereal was only above the kura canopy for part of the season in the lower yielding LM + T-B rotation.

Haynes (1980) stated that the most important plant feature influencing competition for light is height. The taller component of a mixture will always have the advantage. Generally, grasses and cereals are taller than their legume companions in pastures and intercrops. This should result in higher light interception by their canopies (Haynes, 1980). When the cereal canopy was below that of the kura, as in the two LM rotations at Edmonton, it was not as successful at intercepting light. For example, in the LM + B-B rotation, more incident light was available to the kura canopy than the cereal canopy. The wide, horizontal leaves of this clover effectively shaded the cereal plants, reducing their chances of survival. The success of this intercropping system will be influenced by early season competition and whether or not the cereal can quickly grow above the kura canopy.

Barley Root Growth

At Lacombe in Year 1, barley root weights were significantly greater in the barley monoculture (B-B) rotation than the LM + B-B and SLM + B-B rotations (Table 3-7). In Year 2, barley root weights were greater in the cereal monoculture (B-B and T-B) rotations (6.41 and 7.56 g m^{-1}) than the LM+ B-B (1.97 g m^{-1}), LM + T-B (2.21 g m^{-1}), SLM + B-B (3.46 g m^{-1}), or SLM + T-B (3.99 g m^{-1}) rotations. In both years, barley root weights were greater in the SLM than LM rotations.

The reduction in barley root weight in the LM and SLM rotations is most likely due to competition from the kura roots. The barley was seeded into an established clover sward, which possessed a well developed root system. Kura plants produce extremely dense associations of rhizomes and secondary crowns (Peterson et al., 1994). These dense roots would have limited the space available to the barley roots, as well as increasing competition for nutrients and water. Trenbath (1974) postulated that for one component of a mixed pasture to gain the advantage over the other, it would require a fast growing root system. In the cropping system investigated here, the roots of the established kura plants could be growing faster than those of the cereal at the start of the growing season. In some pastures, the grass is thought to have the advantage with its more highly branched rooting system (Evans, 1977). Evans (1977) postulated that most of the clover roots in a mixed pasture would be competing with grass roots, while only a small proportion of the grass roots would compete with the clover. This appears contrary to what occurred in our experiment, as the reduction in barley root weight in the presence of the kura could indicate that most of those barley roots were in competition with the kura roots, while most of the kura roots were not in competition with the barley roots. More research examining the interaction of barley and kura roots is necessary to fully comprehend the interaction between these two root systems.

Conclusion

The suppressed living mulch (SLM+ B-B and SLM + T-B) rotations appear to be preferable to the non-suppressed living mulch (LM + B-B and LM + T-B) rotations for cereal silage production in central Alberta. However, high levels of competition from the kura in the SLM rotations did negatively impact cereal development. Therefore, greater chemical suppression, or combining chemical and mechanical forms of suppression, is necessary to mitigate the negative effects the kura living mulch has on cereal growth.

Early season kura ground cover, as well as canopy height, increased from Year 1 to Year 2 as the stand matured. Kura clover exhibits vigorous spring growth (Bryant, 1974), aided by its extensive over-wintering root and rhizome system (Laberge et al., 2005a). These characteristics combined result in an increase in growth as the kura stands age. Cereal emergence was significantly impacted by the competition from the kura at the time of seeding. Emergence was severely decreased by the presence of the kura living mulch, even in the suppressed (SLM) rotations. However, emergence was higher when the kura had been chemically suppressed. An increased level of suppression before cereal seeding seems to be necessary to maximize cereal emergence.

Shorter kura canopies in the SLM rotations allowed the cereal more access to incident light throughout the growing season at both Edmonton and Lacombe. The kura seemed to dominate the cereals at Edmonton, while the cereal tended to dominate at Lacombe in Year 2. This difference could be attributed to the weather at each site. For example, Edmonton experienced a period of drought when the cereals were seeded in Year 2. The dry conditions negatively impacted cereal emergence and growth, allowing the kura to become the dominant species. At Lacombe, adequate moisture was available at cereal seeding, allowing for good establishment and enhancing the cereal plants' competitive ability.

Barley root weights were greater in the cereal monoculture rotations than either the living mulch (LM) or suppressed living mulch (SLM) rotations. This indicates that the kura is competing below-ground with the cereal plants for water and nutrients in addition to the above-ground competition for light. Suppression of the kura helped reduce this competition in the SLM rotations.

Kura clover living mulches could be adopted for use in cereal silage production systems in Alberta. Further research is required to determine the correct level of chemical suppression of the kura clover living mulch to decrease its competitiveness with the cereal seedlings in the spring. Further work is also necessary in order to better understand the below-ground competition that occurs between cereal and kura roots. The potential benefits of a kura clover living mulch, such as weed and disease control, should be further investigated in order to determine if they mitigate the negative effects of the competition provided by the kura clover living mulch on cereal growth and development.

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Table 3-1. Nitrogen (main plot), Rotation (subplot), and Interaction Effects at the University of Alberta Edmonton Research Station (ERS) for Kura Ground Cover, Early Season Kura Canopy Height, and Cereal Emergence in Year 1 (2006) and Year 2 (2007).

	Kura Ground Cover		Early Season Kura Canopy Height		Cereal Emergence	
Effect	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Nitrogen (N) F test (df=2)	NS	NS	NS	NS	NS	NS
Rotation (R) F test (df=5)	*	***	***	***	***	***
N x R F test (df=17)	NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 3-2. Nitrogen (main plot), Rotation (subplot), and Interaction Effects at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) for Kura Ground Cover, Early Season Kura Canopy Height, Cereal Emergence, and Barley Root Weights in Year 1 (2006) and Year 2 (2007).

	Kura Ground Cover		Early Season Kura Canopy Height		Cereal Emergence		Barley Root Weights	
Effect	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Nitrogen (N) F test (df=2)	NS	NS	NS	NS	NS	NS	NS	NS
Rotation (R) F test (df=5)	NS	***	NS	***	**	***	***	***
N x R F test (df=17)	NS	NS	NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 3-3. Sources of Variation at the University of Alberta Edmonton Research Station (ERS) for Cereal and Kura Canopy Heights and Incident Light Available to the Cereal and Kura Canopies in Year 1 (2006) and Year 2 (2007).

	Cereal Canopy Height		Kura Canopy Height		Incident Light Available to the Cereal Canopy		Incident Light Available to the Kura Canopy	
Effect	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Days After Planting (DAP) F test (df=3)	***	***	***	***	***	***	***	**
Rotation (R) F test (df=5)	***	***	NS	***	***	***	**	*
DAP x R F test (df=23)	***	***	**	***	***	***	***	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 3-4. Sources of Variation at the Agriculture and Agri-Food Research Centre in Lacombe (LAC) for Cereal and Kura Canopy Heights and Incident Light Available to the Cereal and Kura Canopies in Year 1 (2006) and Year 2 (2007).

	Cereal Canopy Height		Kura Canopy Height		Incident Light Available to the Cereal Canopy		Incident Light Available to the Kura Canopy	
Effect	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Days After Planting (DAP) F test (df=3)	***	***	***	***	NS	NS	***	***
Rotation (R) F test (df=5)	***	**	NS	**	NS	NS	NS	***
DAP x R F test (df=23)	***	***	**	NS	NS	NS	NS	**

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 3-5. Kura Clover Ground Cover (%) and Canopy Height (cm) for Six Rotations at the University of Alberta Edmonton Research Station (ERS) and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

	Kura Ground Cover[†]				Kura Canopy Height			
	ERS		LAC		ERS		LAC	
Rotation[‡]	Year 1	Year 2	Year 1	Yea 2	Year 1	Year 2	Year 1	Year 2
	%				cm			
B-B	.	.	.	.	.	.	.	.
T-B	.	.	.	.	.	.	.	.
LM + B-B	67 (0.97)[†]	99 (1.52)	35 (0.63)	95 (1.38)	13	17	9	13
LM + T-B	66 (0.95)	100 (1.55)	29 (0.56)	84 (1.18)	14	18	9	11
SLM + B-B	57 (0.86)	88 (1.22)	28 (0.55)	82 (1.16)	10	14	8	12
SLM + T-B	59 (0.88)	91 (1.29)	27 (0.54)	67 (0.97)	12	14	8	10
SE nitrogen	(0.03)	(0.04)	(0.05)	(0.07)	0.50	0.44	0.87	0.49
SE rotation	(0.04)	(0.04)	(0.04)	(0.05)	0.58	0.51	0.47	0.56
CONTRASTS								
(LM + B-B) vs. (SLM + B-B)	**	***	-	***	***	***	-	**
(LM + T-B) vs. (SLM + T-B)	*	***	-	***	**	***	-	*

[‡] Rotation Treatments are as follows: 1) B-B: barley in Years 1 and 2; 2) T-B: triticale in Year 1, barley in Year 2; 3) LM + B-B: kura living mulch plus barley in Years 1 and 2; 4) LM + T-B: kura living mulch plus triticale in Year 1, kura living mulch plus barley in Year 2; 5) SLM + B-B: suppressed kura living mulch plus barley in Years 1 and 2; 6) SLM + T-B: suppressed kura living mulch plus triticale in Year 1, suppressed kura living mulch plus barley in Year 2.

[†] Kura clover ground cover data was transformed to the arcsin (square root of x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means.

. Data not collected from the plot.

Table 3-6. Cereal Emergence (plants m^{-2}) in Six Rotations at the University of Alberta Edmonton Research Station (ERS) and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

	ERS		LAC	
Rotation	Year 1 (barley or triticale)	Year 2 (barley)	Year 1 (barley or triticale)	Year 2 (barley)
	plants m^{-2}			
B-B	241	116	201	169
T-B	191	100	201	167
LM + B-B	165	35	171	80
LM + T-B	155	35	171	100
SLM + B-B	201	71	182	117
SLM + T-B	172	62	192	147
SE nitrogen	0.68	7.59	7.25	7.51
SE rotation	0.96	9.24	10.26	8.77
CONTRASTS				
B-B vs. T-B	***	NS	NS	NS
B-B vs.(LM + B-B) and (SLM + B-B)	***	***	**	***
(LM + B-B) vs. (SLM + B-B)	***	***	NS	***
T-B vs. (LM + T-B) and (SLM + T-B)	*	***	*	***
(LM + T-B) vs. (SLM + T-B)	NS	**	*	***

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means.

Table 3-7. Barley Root Weights (g m^{-1}) from Six Rotations at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

Rotation	Barley Root Weights	
	Year 1	Year 2
	---------- g m^{-1} ----------	
B-B	8.25	6.41
T-B	.	7.56
LM + B-B	3.24	1.97
LM + T-B	.	2.21
SLM + B-B	5.17	3.46
SLM + T-B	.	3.99
SE nitrogen	1.13	0.82
SE rotation	0.64	0.72
CONTRASTS		
B-B vs. T-B	.	NS
B-B vs. (LM + B-B) and (SLM + B-B)	***	***
(LM + B-B) vs. (SLM + B-B)	**	NS
T-B vs. (LM + T-B) and (SLM + T-B)	.	***
(LM + T-B) vs. (SLM + T-B)	.	*

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means.

. Data not collected from these plots.

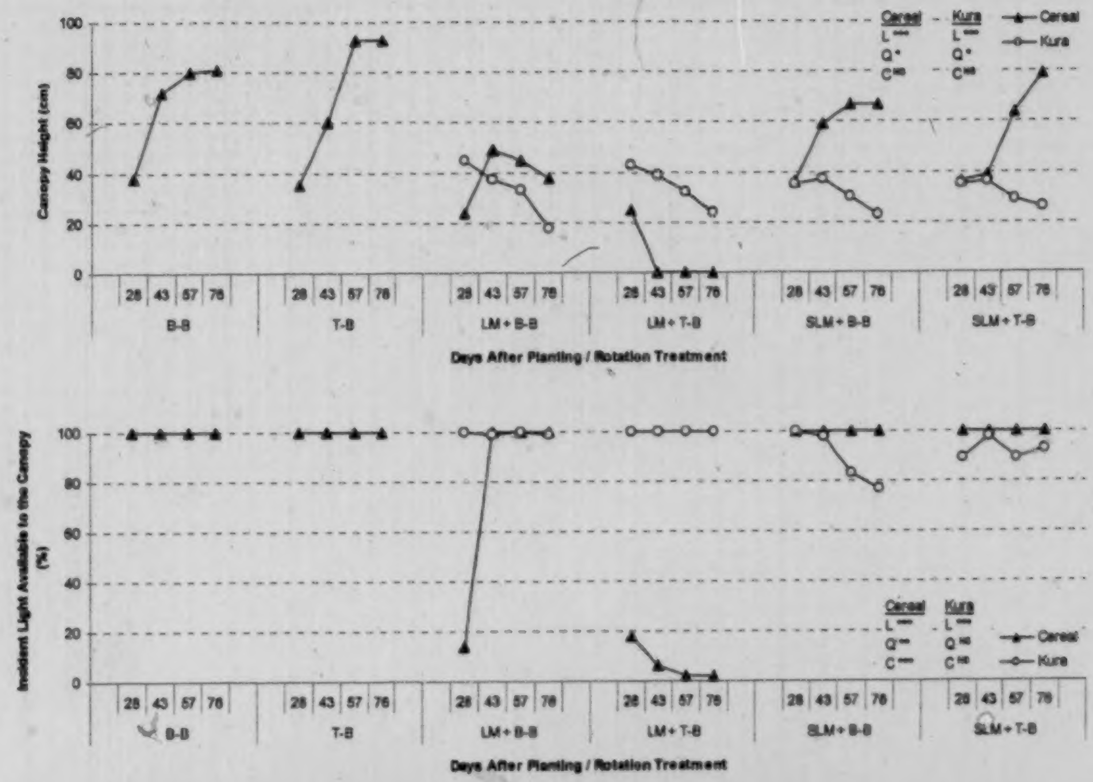

Figure 3-1. Canopy Height (cm) and Incident light Available (%) to the Cereal and Kura Clover Canopies at 28, 43, 57, and 76 days after planting (DAP) for the B-B (barley in Year 1), T-B (triticale in Year 1), LM + B-B (kura living mulch plus barley in Year 1), LM + T-B (kura living mulch plus triticale in Year 1), SLM + B-B (suppressed kura living mulch plus barley in Year 1), and SLM + T-B (suppressed living mulch plus triticale in Year 1) rotations at the University of Alberta Edmonton Research Station (ERS) in Year 1. Data was transformed to the arcsin (square root of x) for analysis and original lsmeans are presented here.

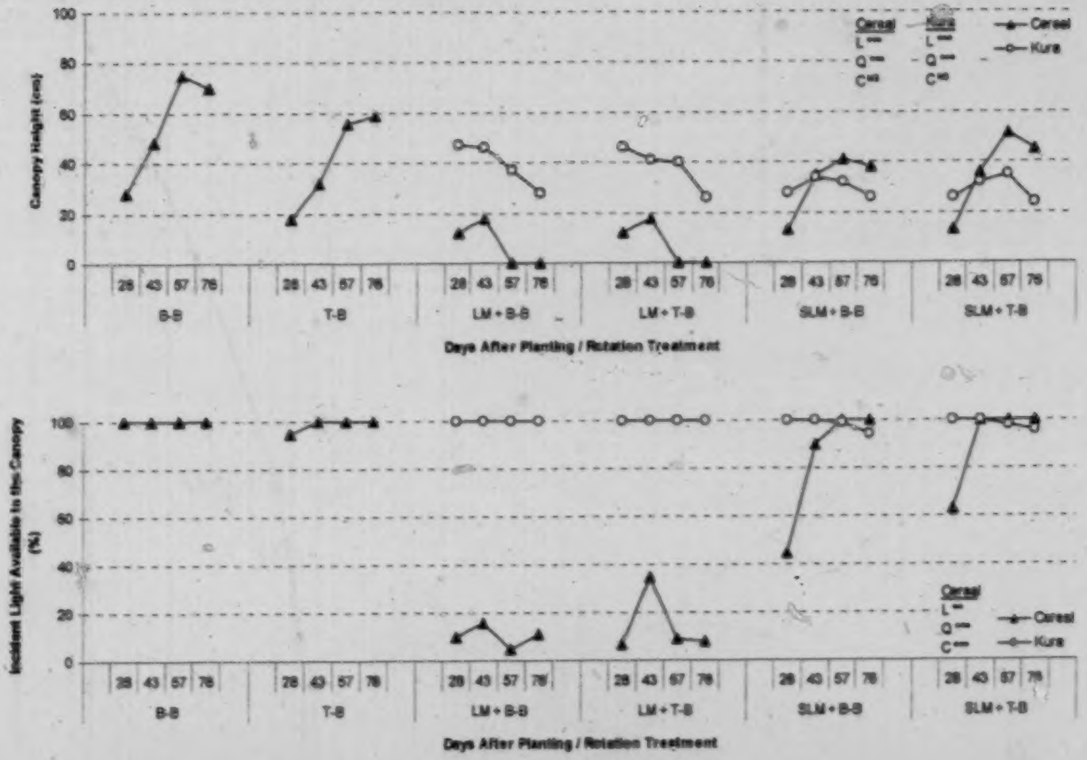

Figure 3-2. Canopy Height (cm) and Incident light Available (%) to the Cereal and Kura Clover Canopies at 28, 43, 57, and 76 days after planting (DAP) for the B-B (barley in Year 2), T-B (barley in Year 2), LM + B-B (kura living mulch plus barley in Year 2), LM + T-B (kura living mulch plus barley in Year 2), SLM + B-B (suppressed kura living mulch plus barley Year 2), and SLM + T-B (suppressed living mulch plus barley in Year 2) rotations at the University of Alberta Edmonton Research Station (ERS) in Year 2. Data was transformed to the arcsin (square root of x) for analysis and original lsmeans are presented here.

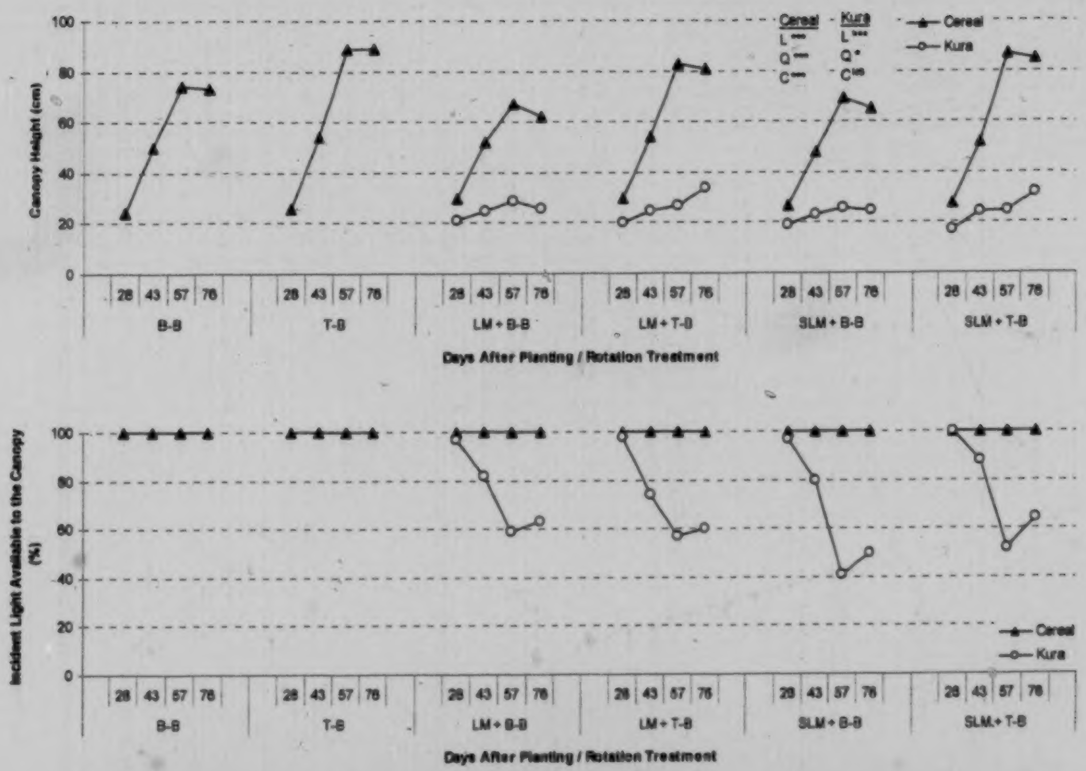

Figure 3-3. Canopy Height (cm) and Incident light Available (%) to the Cereal and Kura Clover Canopies at 28, 43, 57, and 76 days after planting (DAP) for the B-B (barley in Year 1), T-B (triticale in Year 1), LM + B-B (kura living mulch plus barley in Year 1), LM + T-B (kura living mulch plus triticale in Year 1), SLM + B-B (suppressed kura living mulch plus barley in Year 1), and SLM + T-B (suppressed living mulch plus triticale in Year 1) rotations at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1. Data was transformed to the arcsin (square root of x) for analysis and original lsmeans are presented here.

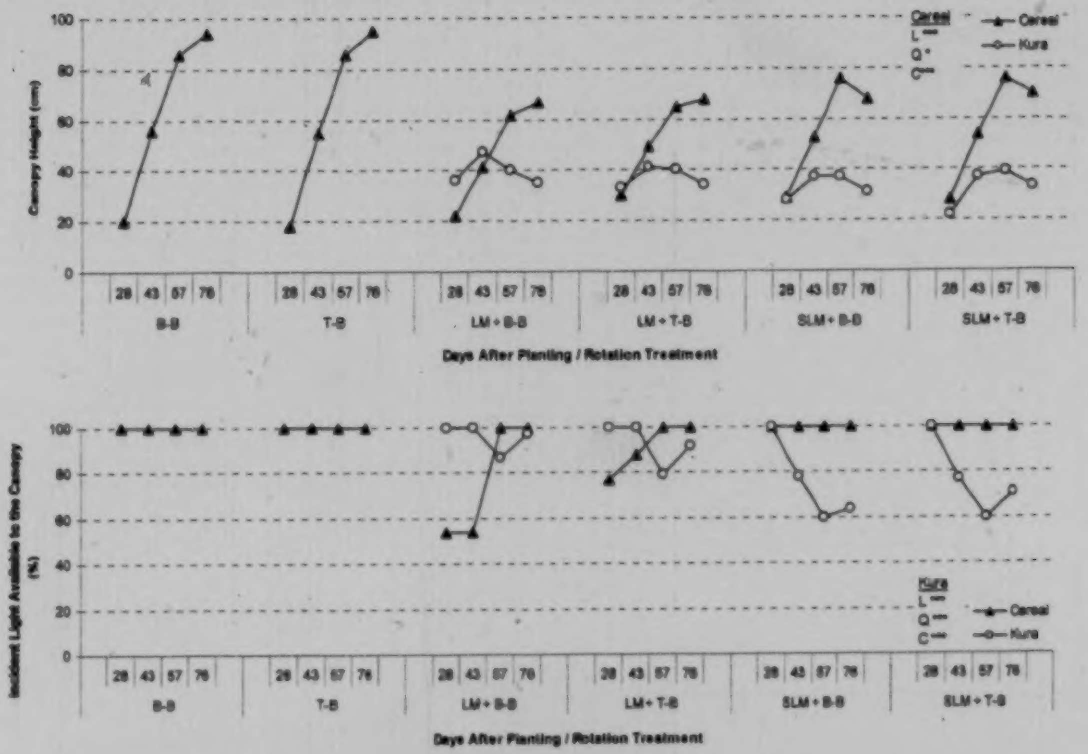

Figure 3-4. Canopy Height (cm) and Incident light Available to the Cereal and Kura Clover Canopies at 28, 43, 57, and 76 days after planting (DAP) for the B-B (barley in Year 2), T-B (barley in Year 2), LM + B-B (kura living mulch plus barley in Year 2), LM + T-B (kura living mulch plus barley in Year 2), SLM + B-B (suppressed kura living mulch plus barley in Year 2), and SLM + T-B (suppressed living mulch plus barley in Year 2) rotations at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 2. Data was transformed to the arcsin (square root of x) for analysis and original lsmeans are presented here.

Chapter Four: Effects of Kura Clover Living Mulches on Weed Pressure and Barley Leaf Diseases

Null Hypotheses

Barley grown following barley will not be significantly different from barley grown following triticale at the same soil nitrogen level for early season weed pressure, weed biomass at harvest, early season leaf disease incidence, and percent penultimate and flag leaf areas infected.

Cereals grown alone will not be significantly different from cereals grown with kura clover living mulches at the same soil nitrogen level for early season weed pressure, weed biomass at harvest, early season leaf disease incidence, and percent penultimate and flag leaf areas infected.

Cereals grown with a suppressed kura clover living mulch will not be significantly different from cereals grown with a non-suppressed kura clover living mulch at the same soil nitrogen level for early season weed pressure, weed biomass at harvest, early season leaf disease incidence, and percent penultimate and flag leaf areas infected.

Introduction

Agri-chemical consumption has been steadily increasing. In Canada, approximately 73% of all farms involved in crop production apply pesticides (Statistics Canada, 2001). On the prairies, 65% of farms in Alberta, 83% in Saskatchewan, and 77% in Manitoba make pesticides part of their production plan (Statistics Canada, 2001). The two main types of pesticides applied are herbicides and fungicides. Pesticides are time-consuming and costly to produce. It can take upwards of 100 million dollars American over nine years to bring a new fungicide to the market (Carlile, 1995). This cost is then passed on to the producer.

The use of these chemicals in crop production has raised numerous environmental concerns. Herbicides can injure non-target organisms, pollute ground and surface water (Conway and Pretty, 1991; Radosevich et al., 1997; Zimdahl, 2004), contaminate soil due to residual properties (Radosevich et al., 1997), and lead to the emergence of herbicide-resistant weeds (Froud-Williams, 1988; Hall et al., 1999). Fungicides do not always provide complete disease control as the target pathogens may develop resistance (Carlile, 1988). Fungicides can also negatively affect beneficial soil micro-organisms (Saskatchewan Agriculture and Food, 1994). In response to concerns related to pesticide application, government policy increasingly focuses on the environmental friendliness of crop production. In Canada, a five-year plan containing specific goals for air and water quality levels, soil structure preservation, and increasing agricultural biodiversity has been developed (Junkins et al., 2005). This movement towards improving agricultural sustainability is prompting producers and researchers to find new methods for decreasing chemical applications in crop production.

Weeds and diseases do need to be controlled, though, in order to mitigate the threat they pose to crop production. Yield losses in wheat due to weed infestations can be as high as 52%, with losses averaging 34% in temperate areas (Oerke and Dehne, 1997). In North America, diseases cause an average annual yield loss of 11.3% (Bailey, 2003). This can lead to economic hardship for producers and consumers. For example, the wheat stem rust outbreaks of 1916, 1927, 1935, and 1954, resulted in 2.72 million tonnes of lost production (Bailey, 2003).

Intercropping offers a potential solution to the problems posed by weeds and diseases. Growing two or more plants at once increases the diversity of the agro-ecosystem. This increased diversity can result in effective weed suppression (Litsinger and Moody, 1976; Hartl, 1989; Trenbath, 1993) and increased disease control (Litsinger and Moody, 1976; Trenbath, 1993; Liebman, 1995). One form of intercropping, called a living mulch, involves maintaining a legume cover crop into which an annual crop is seeded (Altieri, 1995; Zemenchik et al., 1998; Hartwig and Ammon, 2002). Often, that annual crop is a cereal. Kura clover (*Trifolium ambiguum* M. Bieb.), a long-lived perennial legume, is well adapted to a wide range of climatic and soil conditions (Speer and Allison, 1985; Moore, 2003). It is extremely winter hardy and drought tolerant (Speer and Allison, 1985). Kura clover has recently been evaluated as a living mulch for corn (*Zea mays* L.) production (Zemenchik et al., 2000; Affeldt et al., 2004; Duiker and Hartwig, 2004). Zemenchik et al. (2000) found no significant difference in yield between corn grown with a living mulch and conventionally fertilized corn plots, indicating that the kura clover living mulch was supplying the unfertilized corn crop with enough nitrogen to maintain yield.

Little information is available on the effect of kura clover living mulches on weed and disease pressure when grown with cereals for silage production. To date, the majority of studies have been conducted with corn-kura clover living mulch systems in the United States, or with other legumes such as subterranean clover (*Trifolium subterraneum* L.). The objective of this experiment was to investigate the effects of non-suppressed and suppressed kura living mulches grown with barley (*Hordeum vulagre* L.) or triticale (X *Triticosecale wittmack*) on early season weed pressure, weed biomass at harvest, early season barley leaf disease incidence, and infection levels at silage harvest.

Materials and Methods

Treatments and Measurements

Field experiments were conducted at the University of Alberta Research Station (ERS) in Edmonton, Alberta and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC), Alberta. Plots at ERS and LAC were established on black chernozemic soils. Soil pH at the test sites ranged from 6.3 to 7.3. 'Cossack' kura clover plots were established in June 2005 at ERS with a 4-row disc drill, and at LAC with a Conservpak® air seeder (Conserva Pak Seeding Systems, Indian Head, SK). Kura seeding rate was 12 kg ha^{-1}, depth was 1.5 to 2 cm, and row spacing was 30 cm at ERS and 23 cm at LAC. Kura seed was inoculated with a commercially available mixture of *Rhizobium leguminosarum* biovar *trifolii* strains prior to sowing. 'Seebe barley' and 'AC Morgan' oats (*Avena sativa* L.) were seeded at a rate of 300 seeds m^{-2} and row spacing of 23 cm into designated 'kura-free' plots in order to establish the continuous barley and rotational cereal rotation treatments. Soil P, K, and S levels were maintained based on soil test recommendations (Norwest Labs, Edmonton, AB). ERS plots were hand-weeded. In September 2005, both sites were mowed with a sickle mower and the plant material raked off the plots.

The experiment was arranged in a split-plot, randomized complete block design with four replications per site. Sub-plot dimensions were 2.76 x 6 m at ERS and 3.66 x 7.62 m at LAC. Nitrogen was the main plot treatment and rotation was the sub-plot treatment. The three nitrogen (N) application treatments were: (1) low soil N (90 kg N ha^{-1} in Year 1 and 11 to 76 kg N ha^{-1} in Year 2); (2) medium soil N (150 kg N ha^{-1} in Year 1 and 93 to 150 kg N ha^{-1} in Year 2); and (3) high soil N (225 kg N ha^{-1} in Year 1 and 176 to 225 kg N ha^{-1} in Year 2). The six rotation treatments included: (1) B-B (barley in Years 1 and 2); (2) T-B (triticale in Year 1 and barley in Year 2); (3) LM + B-B (kura clover living mulch plus barley in Years 1 and 2); (4) LM + T-B (kura living mulch plus triticale in Year 1 and kura living mulch plus barley in Year 2); (5) SLM + B-B (suppressed kura living mulch plus barley in Years 1 and 2); and (6) SLM + T-B (suppressed kura living mulch plus triticale in Year 1 and suppressed kura living mulch plus barley in Year 2). Glyphosate (0.41 kg a.i. ha^{-1}) was applied to the SLM and the cereal monoculture plots two weeks before seeding. Plot over-sprays of Pursuit Ultra (0.02 kg a.i. ha^{-1} imazethapyr and 0.19 kg a.i. ha^{-1} sethoxydim) for weed control occurred twice in May 2006 at LAC. Pursuit Ultra was used as an overspray as it has no negative effect on kura clover growth.

Cereals were seeded in Years 1 and 2 according to the rotation sub-plot treatments outlined above. They were seeded at a depth of 2.5 to 4 cm, a rate of 300 seeds m^{-2}, and row spacing of 23 cm. Fertilizer (P_2O_5, K_2O, and S) was applied according to soil test recommendations for barley and triticale (Norwest Labs, Edmonton, AB). Nitrogen fertilizer (46-0-0) was applied according to the nitrogen treatments above; broadcast and incorporated during seeding at ERS, or side-banded during seeding at LAC. Seeding occurred at ERS on 23 May 2006 and 24 May 2007; and at LAC on 29 May 2006 and 31 May 2007. At ERS, cereals were seeded perpendicular to the kura. Cereals were seeded between the kura rows at LAC. A 6-row, zero-till disc drill was used at ERS, and a Conservpak air seeder at LAC.

Early season weed pressure was measured at the four-leaf cereal stage. A 1 m^2 quadrat was placed at the front and back of each plot. The weed species and number of seedlings per quadrat were recorded. All weed seedlings that had emerged, or were emerging, were counted. Barley leaf diseases were measured twice during the growing season; at the five-leaf cereal stage and at silage harvest. At the five-leaf cereal stage, fifty 2nd true leaves were examined from plants at two sites per barley-containing plot, and the number with a lesion recorded. Prior to harvest, the percent barley leaf-area infected was measured. Twenty flag leaves and twenty penultimate leaves were randomly removed from each barley plot eight days before harvesting at ERS (July 31, 2006 and August 1, 2007), and fifteen days before the harvest at LAC (August 1, 2006 and July 30, 2007). The percent leaf-area infected of each of those leaves was visually estimated. Cultures of the lesions were taken in order to identify the diseases present. Five flag and five penultimate leaves were randomly selected from each site year. A selection of lesions were randomly cut out of each leaf and placed on moist filter paper in Petri dishes. The lids were placed on the dishes and then into sealed plastic bags. The bags were set under a combination of fluorescent and black light at ambient temperature for four to eight days. After this time, a dissecting microscope was used to view the spores produced on each lesion from the barley leaf samples. If a disease structure could not be visually identified, a sterile needle was used to take a scraping of the structure. The scraping was then placed on a slide with acid fuschin in lactic acid, and viewed under a higher power microscope in order to see the spores for identification.

Plots were harvested at the soft-dough cereal stage (stage 85) (Zadoks et al. 1974). At ERS, plots were harvested on 8 Aug. 2006 and 2007 for barley; and 21 Aug. 2006 for triticale. At LAC, harvests took place on 15 Aug. 2006 and 2007 for barley; and 29 Aug. 2006 for triticale. Weed biomass at silage harvest was determined using a 0.5 x 1 m quadrat placed over three cereal rows per plot. Weed plants were clipped by hand in these quadrates and placed in paper bags. The hand harvested weeds were placed in a forced air dryer for 48 hours at 48 °C, and weighed.

Statistical Analysis

An analysis of variance was performed using the PROC MIXED procedure of SAS (Littell et al., 2006) at $P < 0.05$. Nitrogen level, rotation, and their interaction were considered fixed effects in the split plot analysis. Results for leaf disease incidence and percent leaf area infected were arcsin transformed for analysis according to Steel et al. (1997). Significant nitrogen level effects were separated with orthogonal polynomial contrasts, using coefficients derived in the IML procedure of SAS. Significant rotation effects were separated with preplanned contrasts. Sites were analyzed separately due to significant site x rotation interactions. Years within site were analyzed separately due to significant rotation x year interactions.

Results and Discussion

Nitrogen and Rotation Effects

Nitrogen and nitrogen x rotation did not significantly affect any traits measured at Edmonton or Lacombe (Table 4-1; Table 4-2). At Edmonton, early season weed pressure, weed biomass and early season barley leaf disease incidence were all significantly influenced by rotation, while percent penultimate and percent flag leaf areas infected were only affected by rotation in Year 1 (Table 4-1). At Lacombe, early season weed pressure, early season barley leaf disease incidence, and percent penultimate and flag leaf areas were all significantly affected by rotation (Table 4-2).

Early Season Weed Pressure

There were twenty-two different weed species observed at Edmonton (Appendix 6). The dominant weeds were: stinkweed (*Thlaspi arvense* L.), redroot pigweed (*Amaranthus retroflexus* L.), shepherd's purse (*Capsella bursa-pastoris* L.), lamb's-quarters (*Chenopodium album* L.), and narrow-leaved hawk's-beard (*Crepis tectorum* L.). At Lacombe, eighteen weed species were recorded (Appendix 7). The dominant weeds at this site included: henbit (*Lamium amplexicaule* L.), shepherd's purse (*Capsella bursa-pastoris* L.), perennial sow thistle (*Sonchus arvensis* L.), narrow-leaved hawk's-beard (*Crepis tectorum* L.), and dandelion (*Taraxacum officinale* L.).

At Edmonton, early season weed pressure was greatest in the cereal monoculture (B-B and T-B) rotations (Table 4-3). There were no significant differences in the number of weeds between the living mulch (4 to 11 plants m^{-2}) and suppressed living mulch (6 to 10 plants m^{-2}) rotations. Enache and Ilnicki (1990) found that a living mulch of subterranean clover provided excellent weed control, which supports the weed suppression results of the kura living mulches in this experiment. The T-B rotation had significantly more weeds present than the B-B rotation in both Year 1 (76 vs. 59 plants m^{-2}) and Year 2 (171 vs. 121 plants m^{-2}). In Year 1, the difference in early season weed pressure can be attributed to the different competitive abilities of barley and triticale. Barley is more competitive than triticale (Berkenkamp and Meeres, 1987), and often provides earlier canopy closure. Differences in the number of weeds between these two rotations in Year 2 could be attributed to the carryover effect from the weeds present in Year 1. The greater number of weeds in the T-B rotation would have led to a build up of the weed seed bank in Year 1. A higher number of weeds seeds would then have germinated in the spring of Year 2, resulting in greater early season weed pressure.

At Lacombe during kura clover establishment in 2005, none of the plots were hand-weeded. This resulted in the build-up of the weed seed bank. In order to maintain the trial, Pursuit Ultra was applied twice on all plots prior to cereal seeding in May 2006. Those herbicide applications controlled weeds in the cereal monoculture rotations, but not in the kura LM and SLM rotations. The herbicide droplets were most likely intercepted by the kura leaves in the LM and SLM rotations, reducing the herbicide's effectiveness. This resulted in more weeds being present in the kura LM and SLM rotations (111 to 119 plants m^{-2}) than in the B-B and T-B rotations (41 and 53 plants m^{-2}) when counted in Year 1 (Table 4-3). In Year 2 at Lacombe, the cereal monoculture rotations had more weeds present than the LM rotations (129 and 149 plants m^{-2} vs. 43 and 80 plants m^{-2}). This indicates that the kura living mulch has the ability to suppress weeds. The herbicide suppression in the SLM rotations appears to have reduced the kura's competitiveness and its ability to suppress weeds effectively based on the high number of weeds present in those rotations (147 and 164 plants m^{-2}).

The ability of legume living mulches to suppress weeds is well documented (Enache and Ilnicki, 1990; Teasdale and Daughtry, 1993). Hartwig (1989) found that a living mulch of crownvetch (*Coronilla varia* L. 'Penngift') reduced the number of dandelions present in no-tillage corn. White clover (*Trifolium repens* L.) and subterranean clover living mulches resulted in significant weed suppression in a crop of winter wheat (Hiltbrunner et al., 2007a; Hiltbrunner at al., 2007b). One reason for the success of living mulches at suppressing weeds is that they can influence weed emergence. Teasdale and Mohler (2000) found that as the number of living mulch plants increased, weed emergence decreased. The living mulch canopy reduced light transmittance to the soil surface, which inhibited weed seed germination and seedling growth. Living mulch surface residue can also act as an impediment to weed seed germination and growth. According to Teasdale (1998), decomposing leafy material on the soil surface interferes with light transmittance and may reduce soil temperature, as well as providing a physical barrier to seedling emergence. Competition from the living mulch and decomposing kura leaves likely contributed to the decreased weed pressure seen in kura LM and SLM rotations at Edmonton in Years 1 and 2, and in the LM treatments at Lacombe in Year 2.

Weed Biomass at Harvest

At Edmonton in Year 1, the presence of the living mulch significantly decreased weed biomass in the living mulch + triticale (LM + T-B) and suppressed living mulch + triticale (SLM + T-B) rotations compared to the triticale monoculture (T-B) rotation (Table 4-4). In Year 2, there were significantly lower weed biomasses in the LM and SLM rotations (41 to 191 kg ha^{-1}) than the cereal monocultures (1009 and 1388 kg ha^{-1}). Moynihan et al. (1996) found that annual medic (*Medicago* spp.) intercropped with barley resulted in less fall weed biomass than barley monocultures. The presence of the medic decreased weed biomass by 65% compared with weed biomass from barley monocultures (Moynihan et al., 1996).

At the Lacombe silage harvests in Years 1 and 2, there was no significant difference in weed biomass amongst the six rotation treatments (Table 4-4). This did not reflect the early season weed pressure results, in which the LM and SLM rotations had significantly more weeds present than the B-B and T-B cereal treatments. The disappearance of the difference in weed pressure between the cereal monoculture and LM and SLM rotations at Lacombe indicates that competition from the kura living mulch was able to provide effective season-long weed control, even if weed numbers were high early in the season. Ilnicki and Enache (1992) obtained up to 100% weed control in a corn-subterranean clover living mulch system, equal to that in the corn-herbicide treatments. Living mulches of white clover and birdsfoot trefoil (*Lotus corniculatus* L.) significantly decreased weed biomass in winter wheat (Hiltbrunner et al., 2007b). The biomass of monocotyledonous weeds was 42 kg ha^{-1} in a white clover living mulch treatment compared to 742 kg ha^{-1} in a non-living mulch treatment (Hiltbrunner et al., 2007b). Based on the results obtained here, it appears than an established kura clover living mulch is able to suppress weed growth during the growing season.

Early Season Barley Leaf Disease Incidence

At Edmonton, the presence of the kura living mulch in the LM and SLM rotations significantly reduced the incidence of early season barley leaf diseases compared to the cereal monoculture rotations (7 to 14% and 27 to 43% incidence vs. 36 to 92% incidence, respectively) (Table 4-5). The LM rotations also had a lower incidence of infected leaves than the SLM rotations. This is likely the result of a combination of fewer barley host plants present in the LM rotations and the interception of disease inoculum by the kura plants.

In Lacombe (Table 4-5), the incidence of barley leaf disease lesions was significantly lower in the presence of the kura in the LM and SLM rotations (23 to 76%) than in the cereal monocultures (77 to 91% incidence). At Lacombe in Year 2, the B-B rotation had the highest incidence of lesions, even more than in Year 1. Krupinsky et al. (2004) also found that barley on barley treatments tended to have the greatest occurrence of leaf disease lesions compared to treatments containing crop rotations. In Year 2, the LM rotations had lower lesion occurrence than the SLM rotations.

The presence of the kura plants appears to have had a similar effect on infection rates as crop rotation. In this experiment, the barley plants in the LM + B-B and SLM + B-B rotations had lower or similar incidences of barley leaf disease lesions as barley plants grown in the T-B rotation in Year 2. Crop rotation can break the disease life-cycle and is an effective way to reduce plant diseases (Turkington, 2003). The alternating crops in the rotation may not be hosts to the same diseases, leading to a decline in pathogen populations (Krupinsky et al., 2004). Intercropping increases crop diversity, which helps manage crop diseases. The presence of the second crop, in this case the kura living mulch, can alter the microclimate of the canopy and render it less conducive to disease development (Krupinsky et al., 2002). The presence of the second crop can also interfere with the dispersal of inoculum between its source and the host plants, as well as between host plants (Trenbath, 1993). Ntahimpera et al. (1998) found that the presence of a sudangrass (*Sorghum* spp.) living mulch significantly interfered with the splash dispersal of anthracnose disease (*Colletotrichum acutatum*) conidia. In this experiment, the kura plants were between the soil and the barley plants. The kura canopy most likely acted as a barrier to the movement of disease inoculum, both between the barley residue on the soil surface and the barley leaves above in the LM + B-B and SLM + B-B rotations, and on the dispersal of inoculum between barley plants in the LM + T-B and SLM + T-B rotations in Year 2.

Percent Barley Leaf-Area Infected

Of the barley leaf disease lesions cultured from penultimate leaves at Edmonton, 90% were infected with spot-form net blotch (*Drechsler teres* f. *maculata* Smedeg.) and 10% with speckled leaf blotch (*Septoria passerinii* Sacc.). Of the flag leaves, 25% were infected with spot-form net blotch (*Drechsler teres* f. *maculata* Smedeg.), 15% with spot blotch (*Cocholiobolus sativus* Drechs. Ex. Dastur), 50% with *Clasdosporium* spp., and 100% with *Alternaria* spp..

In Lacombe, 100% of the penultimate and flag leaves were infected with *Alternaria* spp., 90% with spot-form net blotch (*Drechsler teres* f. *maculata* Smedeg.), and 50% with *Cladosporium* spp.. These are all commonly occurring diseases of barley in Canada according to Clear (2003) and Tekauz (2003). Of the diseases found, net blotch is the most economically important. It can cause yield losses as high as 40% in non-resistant barley cultivars on the prairies (Tekauz, 2003). Speckled leaf blotch does not tend to cause serious damage to barley, while barley yield losses due to spot blotch are proportional to the leaf and sheath areas infected (Tekauz, 2003). Cereals infected with *Alternaria* spp. experience a discolouration of the seed called 'black point' due to the growth of this black mold (Logrieco et al., 1990). This can affect seed health. Both *Alternaria* and *Cladosporium* spp. are common saprophytic organisms that would be found on senesced plant material, whether the senescence was due to normal crop ripening or premature ripening due to abiotic or biotic factors.

At Edmonton in Year 1, the barley leaf areas infected on the penultimate and flag leaves were quite low, ranging from 1 to 7% (Table 4-6). The percent leaf area infected in the barley monoculture (B-B) rotation was significantly greater for both the penultimate and flag leaves compared to barley with the kura in the LM and SLM rotations. This indicates that even though the disease occurrence at this site was low overall, the presence of the kura living mulch still significantly decreased infection in the LM and SLM rotations. In Year 2, poor barley emergence occurred in the LM rotations. No penultimate or flag leaves were collected from these rotations, resulting in missing data. There was no significant difference in the percent leaf area infected for both the penultimate or flag leaves between the cereal monoculture (B-B and T-B) and the SLM (SLM + B-B and SLM + T-B) rotations.

At Lacombe, the presence of the kura living mulch significantly decreased the infected area on the penultimate and flag leaves in the LM and SLM rotations (2 to 10% infected) compared to the cereal monoculture rotations (6 to 16% infected) (Table 4-7). In Year 2 at Lacombe, there was no significant difference in infection rates between barley grown on triticale (T-B) and barley grown on barley (B-B).

The presence of the non-host kura material between the barley plants may have restricted the movement of the pathogens from the lower leaves to the upper ones, as is indicated by smaller lesions present on the infected flag leaves in the living mulch rotations (LM and SLM). When diseases are spread via air or water, their distribution among plants in the field is random. Some will land on the host cereal, while others on the non-host legume. Those on the legume will be unable to infect that material, lowering the severity of that disease (Trenbath, 1993). The lower density of barley plants in the LM and SLM rotations reduced the number of host plants available for infection. This may have increased the likelihood of inoculum landing on a kura plant instead of a barley plant, leading to overall lower levels of disease.

Conclusion

A kura clover living mulch system offers numerous benefits to cereal silage production in Alberta. Both the kura living mulch (LM + B-B and LM + T-B) and suppressed kura living mulch (SLM + B-B and SLM + T-B) rotations decreased early season weed pressure compared to the cereal monoculture (B-B and T-B) rotations in Edmonton. This weed suppression was maintained throughout the growing season, resulting in lower weed biomass at harvest. While the presence of the living mulch did not initially decrease weed numbers at Lacombe, the season-long ground cover provided by the kura was effective in suppressing weeds. The end result was a near absence of weeds at silage harvest in August. This weed-suppressing ability of the kura living mulch could decrease the amount of herbicides applied, and subsequently, the production cost for producers. In addition, the reduction in herbicide applications could decrease potential environmental pollution and slow the development of herbicide-resistant weeds.

The LM and SLM rotations significantly decreased the incidence of early season barley leaf disease lesions and the percent penultimate and flag leaf areas infected at harvest. The leaf disease suppression provided by the kura living mulch could reduce yield losses due to decreased infection levels and reduce the need for foliar fungicide applications, lowering production costs. Fewer fungicide applications could also decrease off-target effects and the rate of development of fungicide-resistance in pathogens.

Including the kura clover living mulch could substantially reduce the cost of cereal silage production in Alberta by lowering the need for pesticides to control weeds and diseases. It could also decrease yield losses caused by weed and disease problems. Further research is required to examine the effects of the kura clover living mulch on weed species composition and population shifts, as well as changes in disease populations and soil inoculum levels.

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Table 4-1. Nitrogen (main plot), Rotation (subplot), and Interaction Effects at the University of Alberta Edmonton Research Station (ERS) for Early Season Weed Pressure, Weed Biomass at Harvest, Early Season Barley Leaf Disease Incidence, Percent Penultimate Leaf Area Infected, and Percent Flag Leaf Area Infected in Year 1 (2006) and Year 2 (2007).

Effect	Early Season Weed Pressure		Weed Biomass at Harvest		Early Season Leaf Disease Incidence		% Penultimate Leaf Area Infected		% Flag Leaf Area Infected	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Nitrogen (N) F test (df=2)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rotation (R) F test (df=5)	***	***	**	***	***	***	***	NS	***	NS
N x R F test (df=17)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 4-2. Nitrogen (main plot), Rotation (subplot), and Interaction Effects at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) for Early Season Weed Pressure, Weed Biomass at Harvest, Early Season Barley Leaf Disease Incidence, Percent Penultimate Leaf Area Infected, and Percent Flag Leaf Area Infected in Year 1 (2006) and Year 2 (2007).

Effect	Early Season Weed Pressure		Weed Biomass at Harvest		Early Season Leaf Disease Incidence		% Penultimate Leaf Area Infected		% Flag Leaf Area Infected	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Nitrogen (N) F test (df=2)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rotation (R) F test (df=5)	***	***	NS	NS	***	***	***	***	***	***
N x R F test (df=17)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS, not significant at the 0.05 probability level.

Table 4-3. Early Season Weed Pressure (weeds m^{-2}) for Six Rotations at the University of Alberta Edmonton Research Station (ERS) and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

	Early Season Weed Pressure			
	ERS		LAC	
Rotation‡	Year 1 (barley or triticale)	Year 2 (barley)	Year 1 (barley or triticale)	Year 2 (barley)
	weeds m^{-2}			
B-B	59	121	41	129
T-B	76	171	53	149
LM + B-B	11	4	119	43
LM + T-B	11	7	115	80
SLM + B-B	7	7	111	147
SLM + T-B	6	10	114	164
SE nitrogen	3.06	8.35	14.18	26.77
SE rotation	2.92	10.10	11.31	16.89
CONTRASTS				
B-B vs. T-B	***	***	NS	NS
B-B vs. (LM + B-B) and (SLM + B-B)	***	***	***	*
(LM + B-B) vs. (SLM + B-B)	NS	NS	NS	***
T-B vs. (LM + T-B) and (SLM + T-B)	***	***	***	NS
(LM + T-B) vs. (SLM + T-B)	NS	NS	NS	***

‡Rotation Treatments are as follows: 1) B-B: barley in Years 1 and 2; 2) T-B: triticale in Year 1, barley in Year 2; 3) LM + B-B: kura living mulch plus barley in Years 1 and 2; 4) LM + T-B: kura living mulch plus triticale in Year 1, kura living mulch plus barley in Year 2; 5) SLM + B-B: suppressed kura living mulch plus barley in Years 1 and 2; 6) SLM + T-B: suppressed kura living mulch plus triticale in Year 1, suppressed kura living mulch plus barley in Year 2.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means.

Table 4-4. Weed Biomass at Harvest for Three Nitrogen Treatments and Six Rotations at the University of Alberta Edmonton Research Station (ERS) and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

	Weed Biomass			
	ERS		LAC	
Rotation‡	Year 1 (barley or triticale)	Year 2 (barley)	Year 1 (barley or triticale)	Year 2 (barley)
	$kg\ ha^{-1}$			
B-B	434	1009	40	366
T-B	708	1388	159	207
LM + B-B	301	154	2	83
LM + T-B	179	66	20	0
SLM + B-B	96	41	16	0
SLM + T-B	83	191	8	103
SE nitrogen	114	96	44	185
SE rotation	161	136	62	146
CONTRASTS				
B-B vs. T-B	NS	**	-	-
B-B vs. (LM + B-B) and (SLM + B-B)	NS	***	-	-
(LM + B-B) vs. (SLM + B-B)	NS	NS	-	-
T-B vs. (LM + T-B) and (SLM + T-B)	***	***	-	-
(LM + T-B) vs. (SLM + T-B)	NS	NS	-	-

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means.

- Contrasts not performed due to the absence of a significant rotation effect.

Table 4-5. Early Season Barley Leaf Disease Incidence for Six Rotations at the University of Alberta Edmonton Research Station (ERS) and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

	Barley Leaf Disease Incidence			
	ERS		LAC	
Rotation[‡]	Year 1	Year 2	Year 1	Year 2
	----------	---------- %	----------	----------
B-B	92(1.32)[†]	56 (0.84)	79 (1.10)	91 (1.29)
T-B	.	36 (0.64)	.	77 (1.11)
LM + B-B	7 (0.25)	14 (0.37)	23 (0.49)	56 (0.85)
LM + T-B	.	14 (0.38)	.	49 (0.77)
SLM + B-B	27 (0.54)	43 (0.71)	25 (0.52)	76 (1.09)
SLM + T-B	.	33 (0.61)	.	66 (0.95)
SE nitrogen	(0.04)	(0.05)	(0.04)	(0.06)
SE rotation	(0.04)	(0.04)	(0.04)	(0.08)
CONTRASTS				
B-B vs. T-B	.	***	.	*
B-B vs. (LM + B-B) and (SLM + B-B)	***	***	***	***
(LM + B-B) vs. (SLM + B-B)	***	***	NS	**
T-B vs. (LM + T-B) and (SLM + T-B)	.	***	.	***
(LM + T-B) vs. (SLM + T-B)	.	***	.	*

[†] Barley leaf disease incidence was transformed to the arcsin (square root of x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means for the transformed data.

. Data not collected from these plots.

Table 4-6. Penultimate and Percent Flag Leaf Areas Infected for Barley for Six Rotations at the University of Alberta Edmonton Research Station (ERS) collected before Harvesting in August in Year 1 (2006) and Year 2 (2007).

	Leaf Area Infected at ERS			
	Penultimate Leaf		Flag Leaf	
Rotation‡	Year 1	Year 2	Year 1	Year 2
	%			
B-B	7 (0.26)†	1 (0.11)	2 (0.14)†	1 (0.09)
T-B	.	1 (0.08)	.	0 (0.06)
LM + B-B	2 (0.13)	.	1 (0.10)	.
LM + T-B	.	.	.	.
SLM + B-B	2 (0.13)	1 (0.09)	1 (0.08)	0 (0.05)
SLM + T-B	.	1 (0.08)	.	1 (0.09)
SE nitrogen	(0.02)	(0.05)	(0.01)	(0.02)
SE rotation	(0.02)	(0.04)	(0.01)	(0.02)
CONTRASTS				
B-B vs. T-B	.	*	.	NS
B-B vs. (LM + B-B) and (SLM + B-B)	***	NS	***	NS
(LM + B-B) vs. (SLM + B-B)	NS	.	NS	.
T-B vs. (LM + T-B) and (SLM + T-B)	.	NS	.	NS
(LM + T-B) vs. (SLM + T-B)	.	.	.	.

†Penultimate leaf and flag leaf areas infected were transformed to the arcsin (square root of x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means for the transformed data.

. Data not collected from these plots.

Table 4-7. Penultimate and Percent Flag Leaf Areas Infected for Barley for Six Rotations at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) collected before Harvesting in August in Year 1 (2006) and Year 2 (2007).

	Leaf Area Infected at LAC			
	Penultimate Leaf		Flag Leaf	
Rotation[‡]	Year 1	Year 2	Year 1	Year 2
	%			
B-B	13(0.37)[†]	16 (0.41)	6 (0.24)[†]	7 (0.26)
T-B	.	14 (0.38)	.	6 (0.24)
LM + B-B	6 (0.23)	7 (0.26)	3 (0.17)	2 (0.15)
LM + T-B	.	7 (0.26)	.	3 (0.15)
SLM + B-B	6 (0.24)	10 (0.32)	3 (0.17)	4 (0.19)
SLM + T-B	.	8 (0.29)	.	3 (0.18)
SE nitrogen	(0.03)	(0.03)	(0.02)	(0.02)
SE rotation	(0.03)	(0.02)	(0.01)	(0.02)
CONTRASTS				
B-B vs. T-B	.	NS	.	NS
B-B vs. (LM + B-B) and (SLM + B-B)	***	***	***	***
(LM + B-B) vs. (SLM + B-B)	NS	**	NS	*
T-B vs. (LM + T-B) and (SLM + T-B)	.	***	.	***
(LM + T-B) vs. (SLM + T-B)	.	NS	.	NS

[†] Penultimate leaf and flag leaf areas infected were transformed to the arcsin (square root of x) for analysis and transformed lsmeans are presented in brackets behind the original lsmeans.

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

NS, not significant at the 0.05 probability level.

SE standard error of the difference of two least-squares means for the transformed data.

. Data not collected from these plots.

Chapter Five: Synthesis

Background

My interest in utilizing a kura clover living mulch for cereal silage production in Alberta began after reviewing corn-kura clover living mulch systems in the United States. A living mulch system is a form of intercropping, where the living mulch is an established legume cover crop into which an annual row crop is seeded. Intercropping can improve yield and yield stability, provide control of agricultural pests, and improve soil quality.

Currently, Alberta contains approximately 40% of Canada's cattle herd (Statistics Canada, 2008), and livestock feed is in high demand. Cereal silage tends to be the feed of choice in the Alberta livestock industry. The cultivation of annual cereals for feed is input intensive, with large amounts of synthetic fertilizers and chemicals applied. These applications represent a large portion of a producer's input costs, and may have adverse effects on the environment. Incorporating a kura clover living mulch with annual cereals, such as barley and triticale, for silage production could significantly improve both the environmental and economic sustainability of the production system. To our knowledge, this is one of the first studies of a perennial legume living mulch grown with annual cereals for silage in Western Canada.

Objectives

The objectives of the research conducted were:

1. Examine the effects of suppressed and non-suppressed kura clover living mulches on the yield, species composition, and forage quality of barley and triticale grown for silage at three soil nitrogen (N) levels.
2. Examine the effects of suppressed and non-suppressed kura clover living mulches on barley and triticale emergence, light interception, height, and root growth at three soil N levels.
3. Examine the effects of suppressed and non-suppressed kura clover living mulches on weeds and cereal disease pressure at three soil N levels.

Summary of Findings

Effects on yield, species composition, and forage quality

- Silage yields were reduced when grown with either the kura living mulch or suppressed kura living mulch compared to the cereal monoculture rotations.
- Suppressing the living mulch helped reduce the negative effect of the kura living mulch on silage yield.
- Herbicide suppression of the kura living mulch significantly increased the amount of cereal present in the silage, while reducing the amount of kura clover.
- The kura clover portion of the harvested material was of greater forage quality than the cereal portion.
    - The kura material had higher crude protein levels and lower fibre levels than the cereal biomass.
- The addition of kura to the cereal silage significantly increased the forage quality of the harvested material.
    - The crude protein and relative feed values were significantly higher, and the acid detergent fibre and neutral detergent fibre values lower, in the material harvested from living mulch and suppressed living mulch rotations as compared to the cereal monocultures.
    - The relative feed value of the harvested material from rotations containing the kura clover living mulches ranged from 124 to 158, suitable for high producing dairy cattle at all stages of pregnancy, as well as stocker calves and heifers aged 3 to 24 months. The relative feed values for the material from the cereal monoculture rotations, 99 to 119, are more suitable for dry cows and heifers aged 18 to 24 months (Manitoba Agriculture, Food and Rural Initiatives, 2004).

Effects on cereal emergence, light interception, height, and root growth

- The presence of the kura clover living mulch significantly decreased cereal emergence in both the living mulch and suppressed living mulch rotations.
- Cereal emergence was greater in the suppressed living mulch than the living mulch rotation.

- The dominance of the kura living mulches early in the growing season resulted in lower levels of incident light available to the cereal plants and reduced cereal plant heights at 28 and 43 days after planting (Edmonton in Years 1 and 2, and Lacombe in Year 2).
- Competition from the kura clover living mulch affected barley root growth.
    - Barley root weights were reduced when grown with the living mulches compared to the cereal monoculture rotations.
    - Barley root weights were greater when grown with the suppressed living mulch than when grown with the non-suppressed living mulch.

Effects on weeds and cereal disease pressure

- The presence of the kura clover living mulch significantly decreased early season weed numbers at Edmonton in Years 1 and 2 in both the living mulch and suppressed living mulch rotations, and at Lacombe in the living mulch rotations in Year 2.
- Weed biomass at harvest in the living mulch and suppressed living mulch rotations was significantly lower than in the cereal monocultures at Edmonton in both Year 1 and Year 2.
- The incidence of early season barley leaf diseases was significantly reduced by the presence of kura clover in the living mulch and suppressed living mulch rotations compared to the barley monocultures.
- The percent area of barley penultimate and flag leaves infected with disease just prior to silage harvest was lower in the presence of the kura in the living mulch and suppressed living mulch rotations compared to the cereal monoculture rotations.

Kura Living Mulch Management

- Varying the soil nitrogen did not significantly affect any of the parameters measured, except for silage dry matter yield at Lacombe in Years 1 and 2 (yields increased linearly as the nitrogen level increased).

  - Inherently high soil nitrogen levels at the two sites resulted in artificially high soil nitrogen treatments of 90, 150 and 225 kg N ha^{-1}.
- Barley was the higher-yielding cereal species at Edmonton, while triticale out-yielded barley at Lacombe.
- Herbicide suppression of the kura living mulch before seeding the cereals improved cereal growth compared to the non-suppressed living mulch rotation.
- Regrowth of the kura clover living mulch after the silage harvest ranged from 444 to 1376 kg ha^{-1}DM, with a crude protein content of 17 to 25%.
  - This regrowth could be cut or grazed in order to provide high-quality forage during the fall and winter for cattle.
  - It could also be left on the soil surface or incorporated to increase soil nitrogen level and soil quality.
- The reductions in weed and cereal disease pressure observed as a result of the kura clover living mulches could lead to reduced pesticide costs for the producer.

Further Research

In order to better evaluate the kura clover living mulch system for cereal silage production in Alberta, more research is needed in the following areas.

Location and environment testing

The cereal silage-kura clover living mulch system should be tested in a variety of locations with different climates and soil types across Western Canada. Potential areas include: southern Alberta (brown or dark brown soil zones, longer growing seasons and drier climates), the Peace region of Alberta (grey wooded soils, shorter growing seasons, and wetter climates), areas with high levels of cereal diseases, areas with low soil nitrogen levels, and areas with water-logged soils.

Living mulch suppression

Increased kura suppression is needed in order to enhance cereal establishment. Various herbicides, such as those containing 2, 4-D, dicamba or MCPP/MCPA, at different rates (i.e. 0.5x, 1.0x, 1.5x, and 2.0x) could be tested on established kura living mulches.

Mechanical suppression, such as mowing, light tillage, or using high disturbance seeders, could be investigated. A combination of chemical and mechanical suppression techniques could also be tested in order to discover the best method to decrease early season competition from the kura living mulch.

Fall-seeding cereals

Seeding a fall or winter cereal, such as winter wheat or winter triticale, after a summer harvest may give those cereals a competitive advantage over the kura clover living mulch in the following spring. The kura would be set back at the time of seeding in the late summer due to the removal of its above-ground biomass, and might be slower to regrow while those winter cereals were emerging. The following spring, the winter cereals would be commencing growth at the same time as the kura, and thus may be able to compete better with the living mulch.

Alternative living mulch legumes

Using other perennial forage legumes, such as white clover, birdsfoot trefoil or alfalfa, available in Western Canada is another option. However, these species do have drawbacks. White clover may be too short in stature to be included with the material when harvested, birdsfoot trefoil is short-lived, and alfalfa could experience significant root damage when seeding the cereal. The ideal legume would be: winter-hardy, shade-tolerant, a long-lived perennial, exhibit slow spring growth, and grow at least 20 to 40 cm tall.

Root studies

Underground competition between the cereal and kura roots was not a focus of this experiment. The data collected, however, suggests that the kura clover was interfering with the growth of the barley roots. Further work dedicated to examining the rooting habits and growth of the cereal and the kura living mulch would provide a greater understanding of how the two crop components interact.

Potential for Adoption in Alberta

Kura clover living mulches have the potential to be adopted for cereal silage production in central Alberta. New forage production systems give producers more options when producing quality feed for beef or dairy cattle. The presence of the kura living mulch could decrease the cost of cereal silage production. We have shown that the kura living mulch can suppress both weeds and barley leaf diseases during the growing season. Therefore, in-crop herbicide applications for weed control and fungicide applications for disease control might be reduced with this system.

A potential budget, including the cost of seed, fertilizer, and herbicide applications for three rotations in our study, is presented in Table 5-1. Over the course of two years, the barley monoculture is more expensive in terms of inputs than the living mulch or suppressed living mulch + barley rotations. However, when silage yields and net profit are taken into account, the barley monoculture is the most profitable over the two years, followed by the suppressed living mulch rotation. If the cost of the kura seed was averaged over 5 years, the suppressed living mulch + barley rotation would become more profitable than the barley rotation (net profit of \$572.26 ha^{-1} year^{-1} vs. \$566.30 ha^{-1} year^{-1}, respectively).

With yields averaging less than 1 tonne ha^{-1} and nitrogen content of roughly 3.5%, kura regrowth in the fall following the silage harvest could provide 35 kg N ha^{-1}. This is approximately worth \$21 ha^{-1}. Less N fertilizer would need to be purchased, representing significant savings. However, we would need to investigate how the release of N from the decomposing kura regrowth would synchronize with the fertility needs of the following cereal crop. The savings from fewer pesticide and fertilizer purchases could help offset the yield reductions experienced due to competition from the living mulch.

The major limiting factor to the adoption of this system would be the current limited availability of kura seed and its inoculant. There are only a few seed companies in Canada that have kura seed on hand; most would have to import seed from the United States. Inoculant currently commercially available for kura clover can fail to nodulate the clover, resulting in poor plant growth and establishment. New rhizobial strains for kura clover are being investigated and tested (Seguin et al., 2001).

Producers interested in reducing their chemical applications and production costs, as well as organic producers, would be interested in adopting the kura clover living mulch system. Those with land at risk of wind erosion would also benefit from the year-round ground cover provided by this clover. Dairy and beef producers would be interested in this system due to the increase in quality seen in the material harvested from the living mulch treatments compared to the cereal monocultures. The high crude protein and relative feed values of the material would lead to increased digestibility and better animal productivity, while decreasing the need for protein supplementation.

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Table 5-1. Estimated Production Costs ha^{-1} for Producing Barley Silage in the Barley-Barley, Living Mulch + Barley-Barley, and Suppressed Living Mulch + Barley-Barley Rotations at the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) for Year 1 (2006) and Year 2 (2007).

		Year 1			Year 2		
Input		Barley	LM + Barley	SLM + Barley	Barley	LM + Barley	SLM + Barley
		$ ha^{-1}					
Seed	Kura[‡]	0.00	167.98	167.98	0.00	0.00	0.00
	Barley	49.40	49.40	49.40	49.40	49.40	49.40
N Fertilizer	46-0-0	130.20	42.00	42.00	130.20	42.00	42.00
Herbicide	Roundup Weathermax	10.74	0.00	10.74	10.74	0.00	10.74
	Assert 300 SC	39.35	0.00	0.00	39.35	0.00	0.00
	Refine Extra	15.51	0.00	0.00	15.51	0.00	0.00
Total Cost		245.20	259.38	270.12	245.20	91.40	102.14
Silage Yield (kg DM ha^{-1})		8115	6031	7080	7456	6219	5810
Silage Value[†]		811.50	603.10	708.00	811.50	603.10	708.00
Net Profit (silage value – total cost)		566.30	343.72	437.88	566.30	511.70	605.86

[*] Costs of each input obtained from Statistics and Development Unit, Economics and Competitiveness Division, Alberta Agriculture and Food for Feb. 2008.

[‡] Kura seed costs would have been incurred in the year of establishment (2005), but are included in the costs for 2006 to capture them.

[†] Silage value is based on a price of barley silage of \$35.00 wet Mg^{-1} (or \$0.10 kg^{-1} DM).

Appendix

Appendix 1: Edmonton Research Station Plot Plan

	Low Nitrogen						Medium Nitrogen						High Nitrogen					
Block One	[‡]T-B	LM + B-B	LM + T-B	S LM + T-B	S LM + B-B	B-B	B-B	T-B	S LM + B-B	S LM + T-B	LM + B-B	LM + T-B	LM + B-B	S LM + B-B	LM + T-B	S LM + T-B	B-B	T-B
	Medium Nitrogen						High Nitrogen						Low Nitrogen					
Block Two	LM + T-B	T-B	LM + B-B	B-B	S LM + B-B	S LM + T-B	S LM + T-B	S LM + B-B	T-B	LM + T-B	B-B	LM + B-B	LM + T-B	S LM + T-B	T-B	B-B	S LM + B-B	LM + B-B
	High Nitrogen						Medium Nitrogen						Low Nitrogen					
Block Three	T-B	LM + T-B	S LM + T-B	S LM + B-B	LM + B-B	B-B	LM + B-B	S LM + T-B	LM + T-B	B-B	T-B	S LM + B-B	S LM + T-B	LM + T-B	B-B	T-B	LM + B-B	S LM + B-B
	High Nitrogen						Low Nitrogen						Medium Nitrogen					
Block Four	B-B	S LM + B-B	T-B	LM + T-B	S LM + T-B	LM + B-B	S LM + B-B	LM + T-B	LM + B-B	T-B	S LM + T-B	B-B	S LM + B-B	S LM + T-B	LM + B-B	LM + T-B	T-B	B-B

[‡] Rotation Treatments are as follows: 1) B-B: barley in Years 1 and 2; 2) T-B: triticale in Year 1, barley in Year 2; 3) LM + B-B: kura living mulch plus barley in Years 1 and 2; 4) LM + T-B: kura living mulch plus triticale in Year 1, kura living mulch plus barley in Year 2; 5) SLM + B-B: suppressed kura living mulch plus barley in Years 1 and 2; 6) SLM + T-B: suppressed kura living mulch plus triticale in Year 1, suppressed kura living mulch plus barley in Year 2.

Appendix 2: Climate Data

Monthly precipitation and mean temperatures for May to September at the University of Alberta Edmonton Research Station (ERS) and the Agriculture and Agri-Food Canada Research Centre in Lacombe (LAC) for 2006-2007.

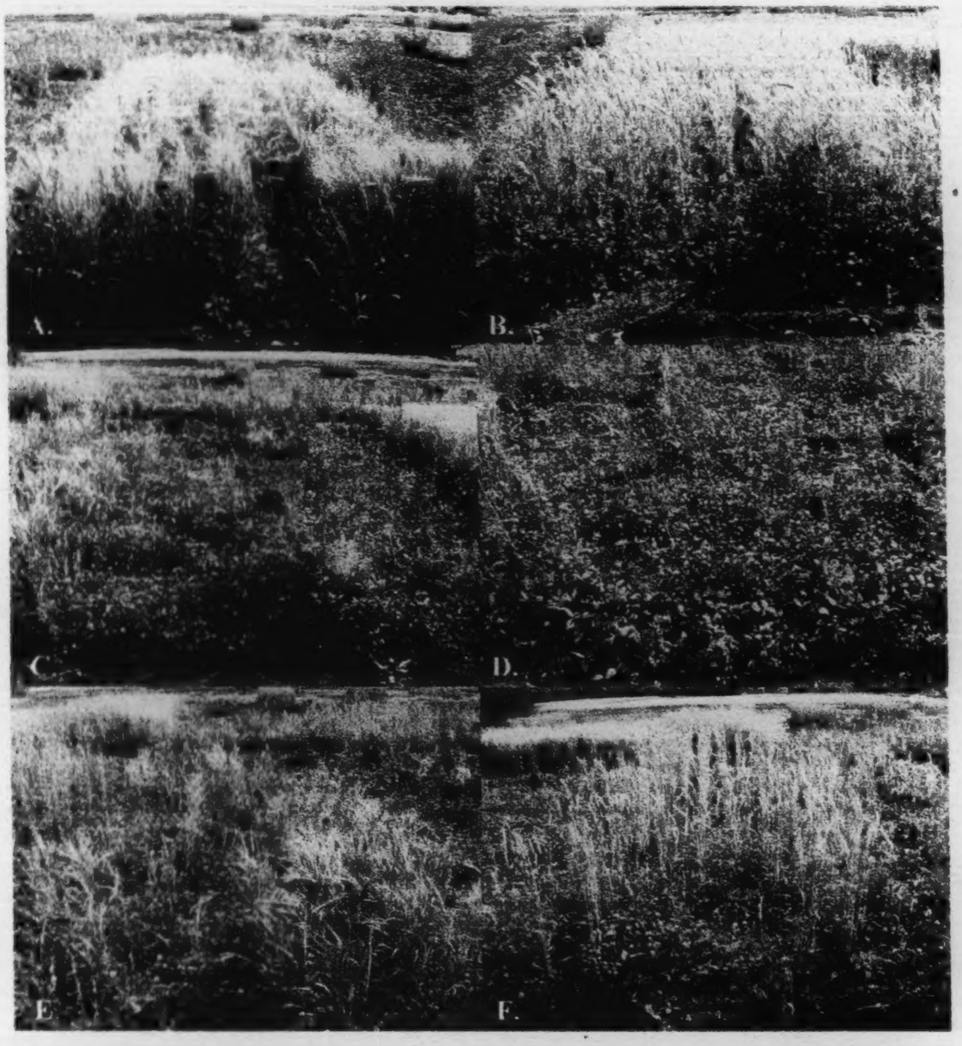
	Weather - ERS			Weather - LAC		
	2006	2007	Norm[†]	2006	2007	Norm[‡]
	Precipitation (mm)					
May	70.6	58.2	43.5	52.0	111.0	50.9
June	63.0	61.2	79.9	81.4	179.1	83.2
July	28.2	51.8	94.3	95.1	55.4	79.0
August	6.1	24.6	67.0	94.5	90.0	65.5
September	2.5	-	41.6	83.4	11.9	42.1
Total	170.4	195.8	326.3	406.4	447.4	320.7
	Mean Temperature (°C)					
May	12.5	11.4	11.6	11.3	9.7	9.8
June	17.0	15.9	15.6	15.3	14.9	13.6
July	19.7	21.0	17.5	17.6	19.3	16.2
August	16.8	15.3	16.6	14.8	13.5	14.9
September	12.5	-	11.1	11.4	9.6	10.1
Mean	15.7	15.9	14.5	14.1	13.4	12.9

[†] Norm is the 30 year (1961-1990) normal at the Edmonton Municipal Airport.

[‡] Norm is the long term average (1961-current) at the Agriculture and Agri-Food Canada Research Centre in Lacombe.

- Data not available.

Appendix 3: Plots at Edmonton at silage harvest on August 8, 2006.



A. Barley in the B-B rotation at harvest.

B. Triticale in the T-B rotation at harvest.

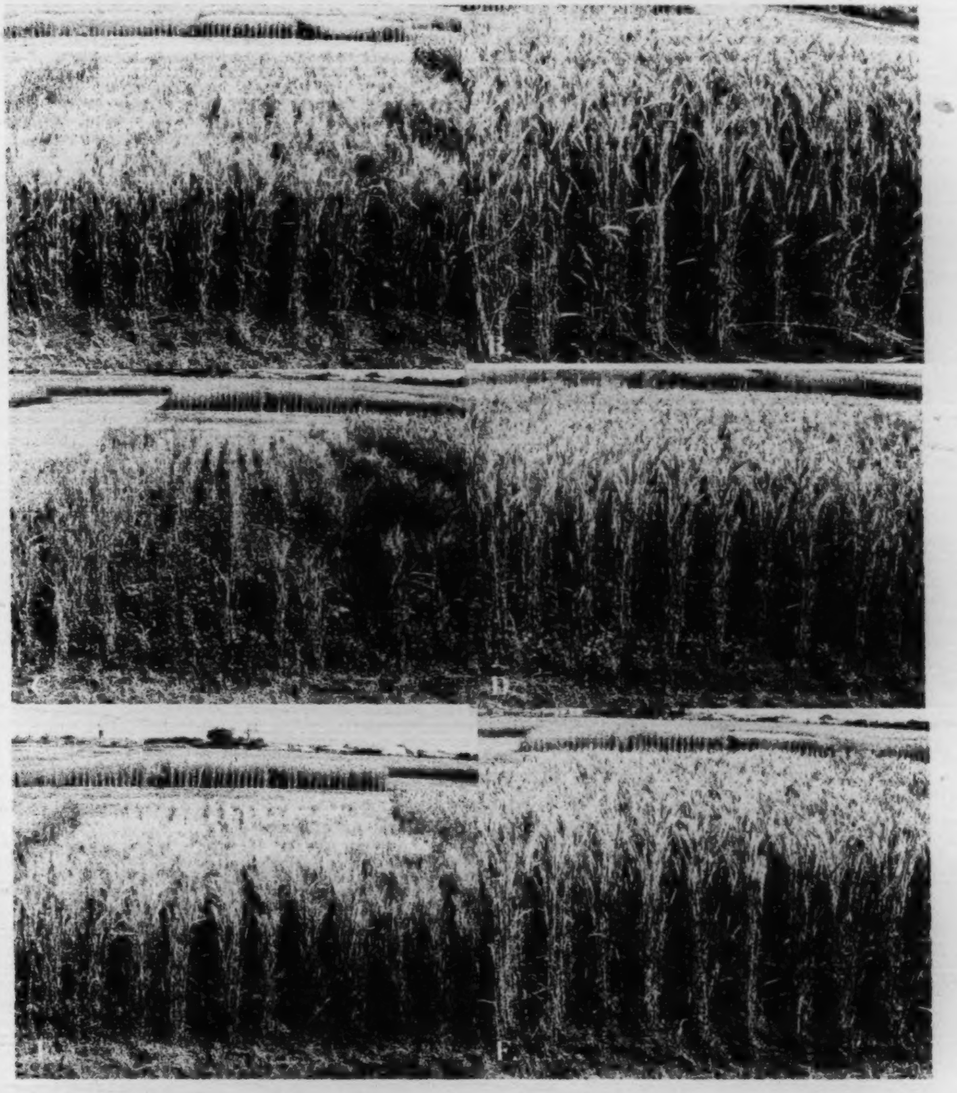
C. Barley and the kura living mulch in the LM + B-B at harvest.

D. Triticale and the kura living mulch in the LM + T-B rotation at harvest.

E. Barley and the suppressed kura living mulch in the SLM + B-B rotation at harvest.

F. Triticale and the suppressed kura living mulch in the SLM + T-B rotation at harvest.

Appendix 4: Plots at Lacombe at silage harvest on August 14, 2006



A. Barley in the B-B rotation at harvest.

B. Triticale in the T-B rotation at harvest.

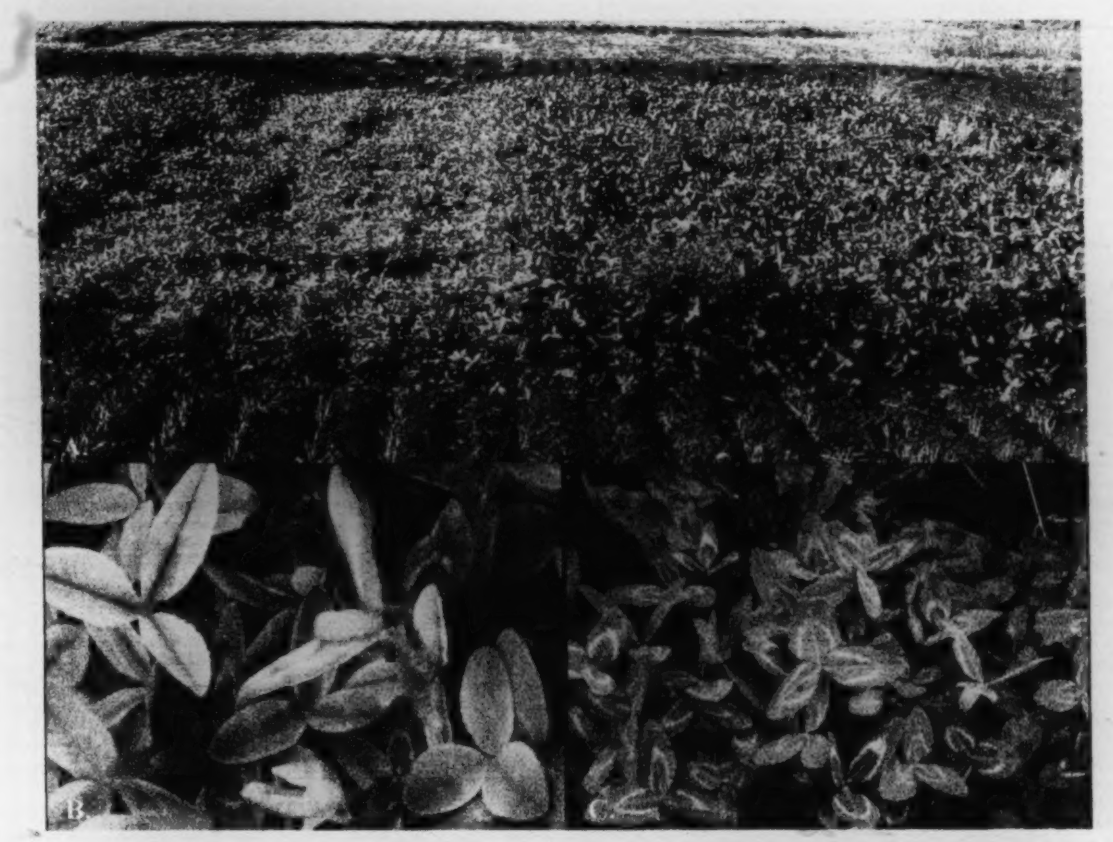
C. Barley and the kura living mulch in the LM + B-B at harvest.

D. Triticale and the kura living mulch in the LM + T-B rotation at harvest.

E. Barley and the suppressed kura living mulch in the SLM + B-B rotation at harvest.

F. Triticale and the suppressed kura living mulch in the SLM + T-B rotation at harvest.

Appendix 5: Herbicide Contrasts



A. Effects of herbicide suppression in the suppressed living mulch (left-hand side) compared the unsuppressed living mulch (right-hand side) ten days after application (May 2007).

B. Close-up of suppressed kura clover (May 2007).

C. Close-up of unsuppressed kura clover (May 2007).

Appendix 6: Weed Species at Edmonton

Weed Species, listed in order from highest to lowest incidence, Counted at the University of Alberta Edmonton Research Station (ERS) in Year 1 (2006) and Year 2 (2007).

Common Name	Latin Name
Stinkweed	*Thlaspi arvense* L.
Redroot Pigweed	*Amaranthus retroflexus* L.
Shepherd's Purse	*Capsella bursa-pastoris* L.
Lamb's-Quarters	*Chenopodium album* L.
Narrow-leaved Hawk's-Beard	*Crepis tectorum* L.
Chickweed	*Stellaria media* L.
Canada Thistle	*Cirsium arvense* L.
Volunteer Oats	*Avena fatua* L.
Dandelion	*Taraxacum officinale* L.
Flixweed	*Descurainia sophia* L.
Common Groundsel	*Senecio vulgaris* L.
Purslane	*Portulaca oleracea* L.
Spiny Annual Sow-Thistle	*Sonchus asper* L.
Perennial Sow Thistle	*Sonchus arvensis* L.
Prickly Lettuce	*Lactuca scariola* L.
Wild Buckwheat	*Polygonum convolvulus* L.
Volunteer Barley	*Hordeum vulgare* L.
Foxtail Barley	*Hordeum jubatum* L.
Pale Smartweed	*Polygonum lapathifolium* L.
Volunteer Canola	*Brassica napus* L.
Broad-Leaved Plantain	*Plantago major* L.
Rough Cinquefoil	*Potentilla norvegica* L.

Appendix 7: Weed Species at Lacombe

Weed Species, listed in order from highest to lowest incidence, Counted at the Agriculture and Agri-food Canada Research Centre in Lacombe (LAC) in Year 1 (2006) and Year 2 (2007).

Common Name	Latin Name
Henbit	*Lamium amplexicaule* L.
Shepherd's Purse	*Capsella bursa-pastoris* L.
Perennial Sow Thistle	*Sonchus arvensis* L.
Narrow-leaved Hawk's-Beard	*Crepis tectorum* L.
Dandelion	*Taraxacum officinale* L.
Chickweed	*Stellaria media* L.
Volunteer Canola	*Brassica napus* L.
Wild Buckwheat	*Polygonum convolvulus* L.
Common Groundsel	*Senecio vulgaris* L.
Spiny Annual Sow-Thistle	*Sonchus asper* L.
Pineapple Weed	*Matricaria matricarioides* L.
Canada Thistle	*Cirsium arvense* L.
Lamb's-Quarters	*Chenopodium album* L.
Smooth Brome	*Bromus inermis* L.
Stork's Bill	*Erodium cicutarium* L.
Flixweed	*Descurainia sophia* L.
Pale Smartweed	*Polygonum lapathifolium* L.
Broad-Leaved Plantain	*Plantago major* L.